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WATER RESOURCES ACTIVITIES IN THE UNITED STATES. WATER REQUIREMENTS FOR POLLUTION ABATEMENT

George W. Reid

Select Committee on National Water Resources, U. S. Senate

July 1960

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WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

WATER REQUIREMENTS FOR POLLUTION ABATEMENT

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS

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STATEMENT BY THE CHAIRMAN

JULY 28, 1960.

To the Members of the Select Committee on National Water Resources:

One of the principal requirements for water in the future is for the dilution of effluent resulting from the treatment of municipal sewage and industrial wastes which are disposed of in our rivers. In addition to the general studies on pollution abatement made for the committee by the Public Health Service and printed as Committee Prints Nos. 9 and 24 it was necessary for use in the overall water supply-demand study that quantitative data be obtained as to the requirements for riverflows for pollution abatement at various levels of waste treatment.

To obtain this information for the committee, I asked the Public Health Service to furnish details on waste treatment costs and water requirements for pollution abatement in all the water resource regions adopted for the committee's studies. The Public Health Service advised the staff informally that this would require so much work that it could not be done by the methods generally in use within the time limit set for the committee's work. However, the Public Health Service agreed to make available the services of one of its consultants, Prof. George Reid, director of the Bureau of Water Resources Research at the University of Oklahoma, to work on the problem. Professor Reid, with advice of technical experts from the Public Health Service, developed shortcut methods for approximating dilution water requirements as a supplemental measure for control of water quality in rivers, and these methods have been used to provide estimates of water requirements for pollution abatement for use in the committee's supply-demand studies. The method is a new one and is highly complex. It is based on extrapolations of methods heretofore used only for dealing with pollution loads in short reaches of river.

Much work needs to be done to refine the new technique developed by Professor Reid in order to make it applicable to specific locations or short river reaches, but for the purpose of the overall objectives sought in the water supply-demand study it provides satisfactory results. Work on refinement of the technique is expected to proceed in the future through a cooperative arrangement between Professor Reid, the Public Health Service, and Resources for the Future.

The report is of such value that I am having it printed as one of our series of committee prints dealing with all aspects of water resources activities in the United States, so that it will be available to all who are interested in this aspect of water resources development.

ROB'T S. KERR,
Chairman, Select Committee on
National Water Resources.

COMMUNICATIONS

THE UNIVERSITY OF OKLAHOMA,
Norman, Okla., August 4, 1960.

HON. ROBERT S. KERR,
Chairman, Select Committee on National Water Resources,
U.S. Senate, Senate Office Building, Washington, D.C.

DEAR SENATOR KERR: I take pleasure in transmitting, for the use of the Senate Select Committee on National Water Resources, a report on "Methods of Approximating Dilution Water Requirements as a Supplemental Measure for the Control of Water Quality in Rivers." This report resulted from your request to the Public Health Service for information on municipal and industrial water supply and waste treatment quantities and costs and other information required by Resources for the Future in connection with the nationwide study of water supply-demand relationships which that organization undertook for your committee. The writer was recruited by the Public Health Service to assist in the development of the required information.

Because of the nature of the study, and of the time limitations imposed, it was found necessary to devise new methods for the rapid approximation of the relationships of riverflows to waste discharges to streams. The estimates produced through this effort are presented in the accompanying report, along with a description of the techniques used in developing them. The procedures followed are included because they may be of interest to other people concerned with water supply-demand relationships and with the problem of low-flow augmentation of rivers, and may stimulate their interest in further exploration of this subject. It must be noted, however, that the techniques followed are necessarily of a tentative nature because of the limitations on the time available for perfecting them. It is hoped that needed refinements can be achieved in the near future as further review suggests revisions.

Staff of the Public Health Service were consulted extensively in the formulation of the techniques used in this study, and were of considerable assistance in refining and improving the final results. In particular, I am grateful to the research staff of the Robert A. Taft Sanitary Engineering Center of the Public Health Service for their critical review of the methods pursued and constructive suggestions, as well as to Mr. Melvin Scheidt of the Washington office of the PHS for his liaison activities and consultation in preparing this report.

I appreciate this opportunity to be of service to you and the select committee. If further information is required, I will be pleased to assist you.

Yours truly,

GEORGE W. REID,
Director, Bureau of Water Resources Research

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METHODS OF APPROXIMATING DILUTION WATER REQUIREMENTS AS A SUPPLEMENTAL MEASURE FOR CONTROL OF WATER QUALITY IN RIVERS

By George W. Reid, Professor, University of Oklahoma

Foreword

As a part of its overall study of national water resources problems, the Senate Select Committee on National Water Resources undertook, through the facilities of Resources for the Future, Inc., a privately supported nonprofit research and study organization, to assess the future supply-demand relationships for water in the various water resource regions of the United States. In approaching its assigned task, Resources for the Future realized the tremendous impact which pollution, and the water requirements for the dilution of treated wastes, would have upon the overall problem of providing water for all purposes, and requested the committee to provide guidance and assistance in estimating future pollution loads, costs of treatment, effects upon available water supplies, and amounts of dilution water required to maintain satisfactory stream quality conditions, on a basinwide basis, for each of the water resource regions of the country. Through the efforts of the U.S. Public Health Service, the writer was recruited to undertake the following study. As first conceived, the required estimates were to be made not only for projections of future population and industrial growth for each basin as a whole, but also for specified river reaches and metropolitan concentrations. The projections of population and industrial growth to be used were prepared by Resources for the Future. Municipal water supply requirements, pollution loadings, and data on sewage treatment costs were provided by the Public Health Service. Streamflow data were provided by the U.S. Geological Survey. Dilution requirements were assumed to be based on maintenance of water quality satisfactory for preservation of aquatic life and other beneficial uses.

Normally, such an analysis requires, for each river basin under study, a considerable amount of time as well as substantial field investigation and survey work. No suitable shortcut method of arriving at satisfactory answers to the detailed questions posed in the projected study was available. Since time was of the essence in the prosecution of the study, it became apparent that something less than perfect answers to the questions posed would have to be accepted. It was, therefore, agreed that efforts should be directed toward development of a technique which could quickly provide an approximation of (1) the order of magnitude of the projected waste disposal problem in relationship to streamflows, (2) the costs of treatment required for various assumed levels of waste treatment, and (3) the amount of dilution water needed, following such treatment, to maintain generally acceptable water quality for each of the water resource regions. This report sets forth the techniques developed for this purpose. Appended, in tabular form are the results of the application of these techniques for each of the 22 water resource regions into which the country was divided.

Because it was impracticable to apply the more detailed data and procedures initially envisioned for the study, the techniques presented are based on more or less arbitrary assumptions with respect to the arrangement or pattern of waste discharges to a stream, and for providing dilution water. These assumptions envision the flow of the river as increasing uniformly from zero at its source to full flow at its mouth, with treated wastes being discharged to the river continuously throughout its length but at no point in greater amount than the river at that point is able to assimilate and still maintain acceptable water quality. Quite

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naturally, these ideal arrangements differ materially from those which, in fact, prevail or may be expected to prevail as a result of actual population and industrial concentrations in each case. Populations and industrial establishments actually occur along river banks in rather large widely spaced concentrations or metropolitan areas, and all waste loadings on streams are therefore concentrated point loadings. The results of the study must, therefore, be looked upon as a rough approximation, to be considered as a point of departure from which to visualize possible attainable goals in water quality management, rather than as actual attainable goals in themselves. Nevertheless, it is believed that these techniques are useful for making a quick appraisal, on an overall basis, of the water supply-demand relationships in any given basin, in terms of potential developable regulated flows versus permissible pollution loadings under the assumed conditions and for varying degrees of treatment and of water quality requirements. The techniques themselves are admittedly imperfect, and will require much additional refinement. It is hoped that, as time permits, these refinements will be developed, in cooperation with the staffs of Resources for the Future and the Public Health Service.

Summary and Conclusions

The results of this study are set forth in tabular form in the appendix of this report. They have been computed for each of the 22 water resource regions into which the country was subdivided. They are also based on three different criteria representative of the several different kinds of pollutants which affect water. These three criteria are concerned respectively with (1) organic oxygen-demanding pollution, (2) plant nutrients, and (3) persistent chemicals. Of these three, it was found that in general the dilution volume required to hold persistent chemicals to acceptable levels of concentration were, in most instances, lower than those required for the dilution of either the biochemical oxygen demand (hereinafter referred to as b.o.d.) or the plant nutrient types of pollutants. Thus, it was concluded that in those instances where, following suitable treatment of the wastes involved, adequate quantities of water could be provided for the dilution of the residual amounts of the latter two types of pollutants, chemical pollution would also be adequately provided for. This is not to say, however, that care is unnecessary in considering chemical pollutants. It is quite conceivable and even probable, that these pollutants may in some basins, or at some future time, become dominant. Furthermore, the effects of many chemicals are, as yet, not fully understood, and their toxic effects, and permissible concentration levels not yet determined. Much research and investigation is needed in this respect. Within the limitations in scope and the time period considered in this report, however, the b.o.d.- and algae-promoting types of pollutants are considered of greatest significance in the majority of the areas, insofar as determination of dilution water requirements are concerned. Dilution quantities for chemical pollutants are, therefore, not included in the appended tabulations although they are discussed in the manuscript itself.

Dilution requirements for the two types of pollutants considered, are tabulated for each of the river basin regions based upon varying degrees of treatment of the raw wastes before discharge to the stream. It will be noted that, as the degree of treatment increases, the dilution requirement for maintenance of dissolved oxygen decreases, but those for the reduction of nitrogen concentrations tend to increase. For the lower treatment levels, the dilution requirements for b.o.d. reduction are controlling, but for the higher levels of treatment, dilution for nitrogen reduction dominates. The break point between these two dilution criteria usually occurs somewhere between the 80 percent and the 90 percent b.o.d. reduction level of treatment, although in some instances it may occur at 70 percent or 95 percent. The break point in each case will, however, indicate the degree of waste treatment for which the minimum volume of dilution water will be required. These relationships are shown in generalized form in figure 1, page 14.

It must be recognized that the results of this study are based on data which are in some instances national averages and that these factors will in fact vary widely between river basins. This fact had to be ignored in this study. Further-

more, no attempt has been made to indicate whether the dilution quantities indicated in the tabulations could, in fact, be provided or, if so, at what cost. This is a function of the larger study being conducted by Resources for the Future, for which these analyses were developed. It seems apparent, however, that in some instances, because of the large volumes of storage required, low-flow augmentation for waste dilution purposes may not be possible or economically feasible. For these situations, alternatives must be sought.

For example, one possible alternative is the lagooning of treated wastes until such time as they can be discharged during high riverflows. Lagooning of wastes may, in some instances, be better than storage of much larger volumes of dilution water. The choice of this alternative naturally rests, however, in the economics of the situation, which must be studied for each particular case.

An example of a second possible alternative which should be studied is, of course, supertreatment or complete removal of all polluting substances, including the reduction of organic pollutants by combustion, and use of ion exchange methods to remove the nutrient material. Effort should also be put into developing processes designed to remove and recover the nitrogen and phosphorus from these waters.

In some situations, and for certain areas, dilution requirements might also be reduced for short periods of time, on the basis of a statistical analysis of streamflow frequencies.

Careful study should be given to all possible alternatives to dilution.

In some instances, it may be found that the river cannot economically provide for all the uses desired, and a choice will be required as to the best possible future use of the river. It is believed that the techniques presented herein provide a useful tool for the rapid approximation of the treated waste dilution requirements of a basin which will be useful in the evaluation of these situations.

Solutions for these problems in the future will also depend in substantial measure on the degree to which new methods of detecting and removing unassimilated wastes are developed. It is important that research into all possibilities for such accomplishment be increased.

Discussion of Techniques and Procedures Followed

Introduction

In attempting to evaluate the impact of future waste water discharges upon the quality of the Nation's receiving waters, it is necessary to consider the effects upon these waters of the several different kinds of pollutants carried by waste discharges. Basically, these pollutants can be separated into five general categories:

1. Organic oxygen-demanding substances, such as domestic sewage and certain kinds of industrial wastes.
2. Infectious agents (bacteria, viruses, parasites, ameba, etc.).
3. Plant nutrients.
4. Persistent chemical, mineral, and radioactive substances which are largely unaffected by existing treatment processes.
5. Heat.

Because of the different effects caused by these several kinds of pollutants, several different criteria are required in evaluating the effects of pollution on stream quality. The five kinds of pollutants enumerated above are not all of the same order of significance, however; consequently, it would be desirable, if possible, to reduce the number of criteria used in this study, in the interest of speed and simplicity. Thus, it must be noted that while, from a public health standpoint, bacterial pollution should, perhaps, have been included, such pollution differs in an important way from the other pollutants in that a high degree of removal can be achieved.

Similarly, heat is not a problem of the same order of magnitude as are the remaining three kinds of pollutants, and methods of reducing heat loads are, furthermore, well known. Heat as a pollution problem is primarily important in connection with biological processes associated with organic pollutants and plant nutrients, although it also affects fish and other aquatic life, and decreases the value of the water for additional cooling purposes. Artificial heat is becoming a serious source of pollution which in a few rivers has already caused a number of problems. It will become increasingly important in future years.

Since, within the limited scope of this study, water temperatures are recognized as a factor in dealing with biological waste treatment processes, however, a criterion concerned directly with heat as a pollutant is not considered to be needed, and no increment has been added for artificial heat. Thus there remain three criteria to be applied in this study.

The first of these criteria is concerned with the ability of a stream to assimilate organic material by bio-oxidation. It is based on the assumption that domestic sewage and organic wastes will continue to increase more or less directly with population growth, but that, in the assimilation of these wastes, the dissolved oxygen content of the receiving waters will at no time be allowed to drop below the level required to support fish. For the examples and illustrations presented in this study, this level is taken to be four parts per million or 4 milligrams per liter (4mg/l), although the technique will permit the use of any desired level.

The second criterion deals with pollution from plant nutrients, mainly nitrogen and phosphorus originating primarily in domestic sewage, but also from some industrial sources. Ordinary treatment processes remove only a fraction of these elements, leaving literally a liquid fertilizer discharged to streams. The use of synthetic detergents containing large amounts of polyphosphates has also increased the phosphorus content in recent years. These elements are not dissolved oxygen depressants but cause pollution by stimulating algal growth. When the algae die, they decompose and cause a secondary oxygen-demanding pollution. The problems of algal growth are of particular importance in domestic water supplies because of the production of taste and odors in the water with resulting abnormal treatment plant operational troubles, in addition to the secondary pollution caused by the death of the algae.

The third criterion should ideally be one which is not a growth promoter, such as nitrogen and phosphorus, and not a pollutant that can be assimilated by nature, but one that is unchanged, and as it accumulates, becomes detrimental to water quality. The organic chemicals, particularly chloroform extractables, have been selected as representative of this category. In addition to the foregoing requirements, they are new and represent in a way something yet to be fully evaluated. Furthermore, their permissible level of concentration is much below the order of level of concentration of some other toxic material, generally being measured in parts per billion. Radioactivity could just as easily be used as a criterion, but the phenomenal growth of the petrochemical industry which produces many of the chloroform extractables promoted the selection of the latter category. Very small amounts of either type of substance are considered detrimental, however.

With respect to this third category of pollutants, it must, of course, be recognized that for irrigation water the most important quality criteria are the dissolved minerals, such as the sodium-calcium-magnesium group—boron, bicarbonates, and heavy concentrations of sodium chloride. Return flows from use of water for irrigation frequently exhibit heavy concentrations of these dissolved minerals, which create a serious problem of water reuse downstream. No attempt was made to use these criteria except with respect to the highly mineralized waters of the Southwest and West. They are proposed only as an alternate and are based on chloride concentrations. In general, concentration limits for the chloroform extractables or radioactive substances are likely to be more rigorous than those for chlorides or similar solids.

It is recognized that in dealing with these three criteria of water pollution, many arbitrary assumptions have been made, but it is felt that they were justifiable in that the results are to be used only for overall nationwide and regional planning purposes. This point of view must, however, be firmly kept in mind in using the technique developed in this report.

DEVELOPMENT OF ANALYTICAL TECHNIQUES

Criterion No. 1. Oxygen-demanding organic wastes

The objective of applying this criterion of pollution is to determine, for various possible degrees of treatment of wastes before their discharge into a stream, the overall ability of the stream to assimilate this type of waste, and, for these situations, to indicate the amount of dilution water which would be required to prevent the concentration of dissolved oxygen at any point in the stream from dropping below the level

established by State requirements.[1] For purposes of this study, 4 parts per million has been used as the criterion to be met. The procedures proposed for dealing with this criterion are as follows:

A. Determination of reoxygenation capacity of the stream.—In a receiving water the interaction of the decomposable organic wastes and the available oxygen can be formulated in differential form as follows: [2]

$$\frac{dD}{dt}=K_1L_a-K_2D \tag{1}$$

D=oxygen deficiency in mg/l (parts per million)
L_a=oxygen demand in mg/l
K_1=decomposition reaction coefficient, to the base e
K_2=reoxygenation reaction coefficient, to the base e
t=time in days

Herein, dD/dt is the rate of depletion or recovery at any one point, and a point-by-point plot will provide the oxygen sag curve resulting from the imposed organic load.

Assuming a condition in which dD/dt is zero, then K_2D, or the permissible pollutional load is equal to the regenerative power of the stream. Assume further that, to properly protect the fishing and recreational aspects of the stream under worst conditions, that is, minimum flow and highest summer temperatures (or winter conditions where freezing occurs), D in that portion of the formula for reoxygenation (K_2D), will not be less than (C_s-4 mg/l) where C_s is the oxygen saturation in mg/l at the appropriate temperature, ionic strength, and elevation above sea level. To formulate total regenerative capacity, it is then necessary to ascertain the values of K_2.

Here, again, it is necessary to emphasize that a great deal of liberty is justified, because accurate K_2 values are not available nor is there enough time to develop them, nor, for that matter, is such accuracy warranted considering the planning level of this analysis. Values for k_2 can be calculated from data on forward velocity and the depth of flow, using the Streeter and Phelps [2] empirical formula:

$$k_2=\frac{eV^n}{H^2} \tag{2}$$

in which e and n are constants
and

$$k_2\text{ (reoxygenation coefficient, base 10)}=\frac{K_2\text{ (base }e)}{2.3}$$

V is the forward velocity
H is the depth

O'Conner [3] has developed a theoretical modification of this formula as follows:

$$k_2=\frac{(D_LV)^{1/2}}{2.31\,H^{3/2}} \tag{3}$$

where
D_L is the diffusion coefficient of oxygen in water
k_2 is reoxygenation reaction coefficient, base 10
H is the depth
V is the forward velocity

In equation (2) values of e and n vary widely and need to be determined, while equation (3) appears to be a good estimate for both nonisotropic and isotropic conditions.

The regional engineers of the PHS made estimates of k_2 values based on their judgment and fitted to the following descriptive table by Fair.[4] [5] (See Table I.)

Values for K_2/K_1 or k_2/k_1 or f for natural water, at 20° C.

Small ponds and backwaters	0. 5–1. 0
Sluggish streams, lakes and reservoirs	1. 0–1. 5
Large streams (low velocity)	1. 5–2. 0
Large streams (normal velocity)	2. 0–3. 0
Swift streams	3. 0–5. 0
Rapids and waterfalls	5. 0

The average summertime temperatures are taken from work of Collins, in plate IX of the Water Supply Papers.[6] The k_2 values as affected by temperature are corrected by the following formulas:

$$k_2(T)=k_2(20)\times1.016^{(T-20)} \tag{4}$$
$$k_1(T)=k_1(20)\times1.047^{(T-20)} \tag{5}$$
$$f(T)=f_{(20)}=0.97^{(T-20)} \tag{6}$$

These data are shown in table I.

[1] It must be noted that this approach is not intended to imply that dilution is proposed as a substitute for proper waste treatment. Rather it is intended to develop the dilution quantities needed after treatment to produce river water of satisfactory quality.

[2] "A Study of the Pollution and Natural Purification of the Ohio River III," Streeter and Phelps, PHS, Bulletin 146, 1925.

[3] "Oxygen Relationships in Streams," USPHS, Technical Report W58-2. 1958, p. 35.

[4] "Sewage Treatment," Imhoff and Fair, Wiley, 2d edition, 1956, p. 306.

[5] k_1 calculations could be made from representative stream data where:

$$\frac{dw}{dt}=K_2\times A\times D\times2.72\times H \text{ where } \frac{dw}{dt}=\text{pounds of oxygen per day}$$

K_2 reaeration coefficient to the base e
H means depth, feet
A area, acres.

[6] "Temperature of Water Available for Industrial Use in the United States," Water Supply Paper 520-F, USGS, 1925.

TABLE I.—*Reoxygenation data*

Water resource region	Mean velocity [1] (miles per hour)	Average water [1] depth	Average stream length (miles)	USPHS k_2/k_1 estimates at 20° C. (68° F.)	Summer temperature, ° F.	k_1 [2] estimates	n [3]
New England	1½	4.0	100	([4] 2.8)	70	0.28	1.0
Delaware-Hudson	1½	3.0	75	([4] 3.5)	70	.36	2.5
Eastern Great Lakes	1½	3.0	50	2.7	68	.27	2.0
Western Great Lakes	1½	3.0	50	2.0	70	.20	1.7
Chesapeake Bay	1½	5.0	75	([4] 2.0)	73	.22	3.0
Ohio	1	4.0	100	2.5	75	.30	7.0
Cumberland	1½	3.0	100	([4] 2.8)	73	.31	2.0
Tennessee	1½	4.0	75	1.5	78	.16	4.0
Southeast	1½	5.0	150	2.0	83	.24	2.0
Upper Mississippi	1	3.0	150	1.5	74	.17	4.6
Lower Mississippi	1½	4.0	150	([4] 2.8)	80	.32	3.3
Upper Missouri	1½	3.0	250	2.5	68	.25	1.0
Lower Missouri	1	3.5	125	2.5	74	.29	3.2
Upper Arkansas and Red	1½	2.0	200	2.0	78	.23	0.75
Lower Arkansas, Red, and White	1½	3.5	175	2.0	82	.24	2.0
Western Gulf	1	4.0	300	2.0	85	.25	1.0
Rio Grande and Pecos	1½	1.5	140	2.0	83	.24	1.0
Colorado	1	2.0	150	2.5	80	.29	2.0
Great Basin	1	1.0	100	1.7	75	.25	1.0
Pacific Northwest	1	4.0	150	2.5	65	.25	2.0
Central Pacific	1½	4.0	100	4.0	68	.40	3.0
South Pacific	1	3.5	50	1.3	83	.16	1.0

[1] Supplied by the U.S. Geological Survey.
[2] k_2, k_1 adjusted to stream temperature using k_1 as 0.1, at 20°C.
[3] See p. 7 for description of n.
[4] Computed by reference O'Conner equation and other streams

TABLE II.—*Future municipal water requirements* [1]

[Million gallons per day]

Water resource region	1980			2000		
	Low	medium	High	Low	medium	High
New England	1,230	1,477	1,724	1,255	2,022	2,789
Delaware and Hudson	3,247	3,753	4,259	3,750	5,301	6,869
Chesapeake Bay	1,232	1,440	1,648	1,495	2,193	2,872
Eastern Great Lakes	2,350	2,763	3,144	2,710	4,052	5,390
Ohio	2,100	2,374	2,745	2,285	3,471	4,694
Cumberland	101	119	137	108	163	229
Tennessee	252	311	370	259	331	616
Southeast	1,516	1,832	2,148	1,810	2,818	3,826
Western Great Lakes	2,860	3,360	3,860	3,010	4,593	6,612
Upper Mississippi	1,503	1,759	2,033	1,637	2,535	3,433
Lower Mississippi	325	387	449	360	546	732
Upper Missouri	514	618	722	544	867	1,190
Lower Missouri	242	279	316	254	368	491
Upper Arkansas, White, and Red	361	419	477	382	481	760
Lower Arkansas, White, and Red	291	341	391	304	432	566
Western Gulf	1,135	1,275	1,415	1,437	1,907	2,380
Rio Grande-Pecos	139	159	179	201	270	339
Colorado	344	397	449	452	647	831
Great Basin	300	345	390	422	579	736
Pacific Northwest	1,197	1,402	1,697	1,532	2,262	2,991
Central Pacific	1,579	1,693	1,807	1,954	2,715	3,476
South Pacific	1,983	2,175	2,368	2,726	3,420	4,114
Total	24,801	28,588	32,638	29,887	42,543	55,936

[1] From pt. I of USPHS report to the Senate Select Committee on National Water Resources, 1960 (Committee Print No. 7).

Adequate USGS data were not available for computing k_2 values using the O'Conner formula Furthermore, these values will change, as storage and regulation change the flow characteristics of the stream, a factor which is recognized but which has not been provided for in these computations. This effect must be dealt with however, in future studies. Another factor which must be recognized is that k_2 does not represent the entire picture insofar as the reoxygenation of the water course is concerned. There are other equally important factors such as photosynthetic reoxygenation, benthol oxygen demand, volatilization and loss of b.o.d. to the atmosphere, longitudinal mixing and loss by sedimentation, which in many other works are represented by a term called k_3. It is also noteworthy that the increasing quantities of phosphates being discharged to the river through the use of organic detergents is changing the surface tension of the water, which in turn will detrimentally affect the reaeration of water. Values of f from Fair [7] formulation (6), above, do take into account all these other factors, including whatever phenomena influence the reoxygenation and deoxygenation in a stream.

It is questionable whether formulas (4) and (5) represent accurately the effects of temperature. For the range of temperatures of the water used in this study, the coefficient of 1.047 seems to be reasonably accurate for formula (5). Values for k_2 range from 1.016 to 1.047. As recent studies indicate, 1.02 would probably be the most logical value to use in the absence of additional information. The value of 1.016 was used, however because it correlated with the value that Fair had originally used in his temperature relationships for f values as computed by formula (6). Computed values of k_2 could probably have been used, and possibly would have been

[7] "Sewage Treatment," Imhoff and Fair, Wiley, 2d edition, 1956, p. 304.

more consistent with velocities and depths but the experience of the USPHS field engineers was considered preferable.

The foregoing statements concerning the values k_2 and k_1 and their relationship with water temperatures and the solubility of oxygen further emphasize the limitations in their use for exact analysis.[8] It is felt, however, that the data available are accurate enough for the planning level type conclusions that are here being sought.

With k_2 adjusted to worst temperature condition, daily reoxygenation is computed as follows:

$$\text{mg/l of oxygen/day} = k_2 \times D \times 2.3 \qquad (7)$$

B. Determination of total basin flow to reoxygenation capacity.—It now becomes necessary to express the reoxygenation capacity of the stream in terms of the terminal flow, Q, of the basin, at the mouth, for given values of D, k_2 and reoxygenation requirements. Reoxygenation in pounds per day is as follows:

$$\text{pounds of oxygen per day} = 2.3 \times k_2 \times D \times 8.3 \times Q \times \frac{n}{3} \times \frac{L}{V} \qquad (8)$$

Actually, $\frac{QnL}{3V}$ represents the volume of water effectively operative in the reoxygenation process. This volume is idealized as being a pyramid with its peak representing the source or origin of the stream, a height equal to the average stream length, L, in miles, and base equal to the terminal flow (Q), of the stream, expressed in millions of gallons per day (mil.g.d.) divided by the velocity, V, expressed in miles per day.

The USGS has provided values for L and V (see table I), the velocity being determined by the Leopold and Maddock generalized formulation.[9] The value of L is the summation of total length of all streams in a basin divided by the number of streams, or the average stream length. The quantity n represents the number of reoxygenation volumes based on the terminal flow of the entire basin, Q. Using the Ohio as an example, all of the tributaries together will have a volume equal to one-third of the average length of all the tributaries (L) times the terminal flow of the whole river, Q, divided by V, or $\frac{QL}{3V}$. The volume of the main stem is equal to the effective reach of the main stem less the last individual tributary basin of average length, L, times the terminal flow. Here, it must be remembered, of course, that the computation of L includes the main stem; thus for the Ohio:

$$n = \left(\frac{R-L}{L} + 1\right) \text{ or } n = \left(\frac{700-100}{100} + 1\right) = 7.0$$

This quantity, derived by computations, is used as a guide. Actually, considerable judgment as to the various other factors involved is required in estimating n, so that the value of n for each basin must be finally established more or less by inspection. For basins with many rivers and no real main stem, like the New England Basin, n will equal one, while basins with long main stems will have higher n values. For a given flow, the latter type of stream arrangement will, of course, produce more oxygen and accommodate more organic material than the former. The values of n finally selected for the various river basins are shown in table I.

In the case of the Ohio, a value for n of 7.0 is the same as using an effective time of 31 days, or a model with an 800-mile reach and an approximate average velocity of 1 m.p.h. This is considered conservative, because the so-called pyramid of water volume would actually have convex sides.

It is assumed that at no point along the stream will pollution be added at a greater rate than can be accommodated by reoxygenation. In general, this means that the population equivalent [10] load will be distributed along the stream in a fixed ratio to its reoxygenation capacity. If this is not done, then the equation does not apply, but such a method of loading would be the most economical way of utilizing a stream's oxygenation capacity.

[8] This analysis could have been undertaken by reaches using the appropriate values of k_2, Q, V and L for each reach and then taking a percentage of the pounds of oxygen produced per day for each reach as a function of the percentage flow time in the reach. The flow time being the reach length (L) divided by the velocity V or (L/V).

[9] U.S.G.S. Professional Paper 252.

[10] For purpose herein, p.e. will refer to population equivalent and P.E. will refer to million population equivalent.

C. Estimating the anticipated pollution loadings.—With the regenerative capacity of the stream estimated, it is necessary to determine the population equivalents of the anticipated pollution loadings in the several water resource areas of the country. This has been done by the PHS in its report to the Senate select committee (Committee Print No. 9) and is reproduced in table III. These estimates are based on municipal discharges and do not include direct industrial waste discharges, although they do include industrial wastes discharging through municipal systems. Accordingly, it is necessary to increase these amounts by a reasonable estimate of the industrial wastes discharged directly to the streams. RFF has supplied estimates of future industrial waste discharges as well as the distribution of these wastes, by basin, for 1954. Rudolfs [11] reported the total industrial waste being produced in 1954 as 134,300,000 p.e. His subgroupings were reworked to fit the RFF categories. (See table IV following.)

TABLE III.—*Projected municipal sewage waste discharges in continental United States, by water resource region, in terms of equivalent population (P.E.)* [1]

[Millions]

Basin	1954 actual	1980			2000		
		Low	Medium	High	Low	Medium	High
New England	4.8	0 5	4.0	4.9	2.2	3.3	4 7
Delaware and Hudson	12.3	11.5	12.7	14.7	8.9	11.2	14 8
Chesapeake Bay	4.2	4.5	5.2	6 3	3.8	5.3	7 3
Eastern Great Lakes	6.1	5.9	6.8	7 8	4.7	6 4	8 9
Ohio	7.8	7.1	8.5	10.3	5.2	7.9	11.5
Cumberland	.4	.3	.4	.5	.2	.3	.5
Tennessee	.9	.8	.9	1 3	.5	.9	1.3
Southeast	5.8	5.1	7.6	1.0	5.0	7 9	11 8
Western Great Lakes	6 0	5.8	6 7	8 1	4 6	6.5	9 1
Upper Mississippi	4.6	4.1	5.0	6.1	2.9	4.5	6.7
Lower Mississippi	1.3	1.2	1.4	1.8	.8	1.3	1 9
Upper Missouri	1.8	1.6	2.0	2.5	1.0	1.7	2.6
Lower Missouri	.9	.7	.9	1.0	.4	.7	9
Upper AWR	1.4	1.4	1.6	1.9	1.0	1.4	2 0
Lower AWR	1.3	1.0	1 2	1.5	.6	.9	1 3
Western Gulf	3.7	4.6	5.1	5.9	4.0	5.0	6 3
Rio Grande-Pecos	.5	.5	.6	.7	.5	.8	1.0
Colorado	.7	.9	1.1	1.3	.9	1.2	1 6
Great Basin	.5	.6	.7	.8	.6	.8	1.1
Pacific Northwest	2 2	2.3	2 8	3 3	2 1	3.0	4 3
Central Pacific	3 5	5.0	5 5	6 3	5 1	6 4	8 4
South Pacific	4.4	5.7	6 1	7.0	5 3	6 5	8 5
U.S. total	75. 0	71. 8	86. 8	103. 4	60 3	83. 8	117. 1

[1] From Committee Print No. 9, Senate Select Committee on National Water Resources, 1960. Based on 70 percent treatment in 1980 and 80 percent treatment in 2000.

[11] Rudolfs, Wm., "Industrial Wastes—Their Disposal and Treatment," ACS Monograph Series No. 118, p. 3 (1954).

TABLE IV.—*Estimates of directly discharged major oxygen consuming industrial wastes in year 1954 and PHS estimates of increased waste production by year 2000 (population equivalents in millions) based on nontreatment*

	P.E. produced 1954	Increase in percent by 2000
Food	68 5	200
Pulp and paper	43. 6	800
Chemicals	14 6	1,000
Petrochemicals	3 5	400
Others	4. 2	
Total	134. 4	475

The directly discharged wastes produced in each basin in 1954 were next computed by applying, for each type of product, the appropriate percentage of national production attributable to that basin, to the national total waste discharge for each category of waste, as determined by the RFF studies. The waste production by basin in years 1980 and 2000 was then computed by multiplying each category by the RFF estimate of increase in such waste flow for these years. (Where a portion of the basin discharges into either salt water, the Great Lakes or the Great Salt Lake, the waste P.E. to the stream was reduced by the ratio of population with pollution load being discharged to these bodies in 1960 to the total 1960 population estimate for the basin. These values were furnished by the PHS.) The calculations for untreated industrial wastes produced in the Ohio River Basin are presented, as an example, in the following table:

TABLE V.—*Projected industrial wastes produced* [1] *in the Ohio River Basin*

	1954			1980		2000	
	Nation P.E.[2]	Ohio		Increase over 1954 (percent)	P.E.[2]	Increase over 1954 (percent)	P.E.[2]
		Percent of nation	P.E.[2]				
Food	68.5	11.1	7.6	130	9.8	240	18.1
Pulp and paper	43.6	3.0	1.30	160	2.1	410	5.3
Chemicals	14.6	12.0	1.75	380	3.2	870	15.3
Petro-chemicals	3.5	7.8	.26	180	.5	250	.6
Total					15.6		39.3

[1] Estimates are for gross wastes without treatment.
[2] P.E. are in millions.

These data, for all the basins, are shown in table V.

TABLE VI.—*Projected industrial wastes produced*[1] *in the U.S. by water resource region*

[The portion discharged directly to lakes, oceans, or gulfs has been deleted]

[P.E. in millions]

Water resource region	1980			2000		
	Low	Medium	High[1]	Low	Medium	High
New England	15.3	19.5	26.6	27.2	43.0	75.2
Delaware and Hudson	9.1	10.8	13.7	13.9	18.1	28.2
Chesapeake Bay	16.6	24.2	28.0	28.3	39.0	71.6
Eastern Great Lakes	9.9	13.0	16.5	14.7	33.2	37.0
Ohio	12.9	15.5	37.6	26.1	39.4	61.9
Cumberland	2.7	2.9	4.8	5.0	5.6	12.8
Tennessee	3.9	6.4	8.5	9.9	15.4	25.2
Southeast	4.6	11.8	14.8	10.3	20.3	39.6
Western Great Lakes	17.2	20.1	26.2	14.5	22.2	36.1
Upper Mississippi	15.7	18.1	24.6	20.5	30.8	50.2
Lower Mississippi	7.1	8.9	11.6	20.1	29.9	50.9
Upper Missouri	10.0	11.7	14.2	15.6	18.0	26.4
Lower Missouri	2.3	2.8	3.8	5.4	6.8	14.5
Upper Arkansas and Red	2.1	2.6	3.6	3.8	4.7	5.8
Lower Arkansas, White and Red	3.4	4.7	5.9	6.4	10.2	17.2
Western Gulf	11.5	14.3	19.0	26.0	36.6	62.8
Rio Grande-Pecos	1.5	2.1	3.4	3.0	4.2	7.8
Colorado	1.1	1.1	2.2	3.6	5.5	10.3
Great Basin	4.0	4.4	4.9	5.6	5.8	6.4
Pacific Northwest	53.1	60.0	96.0	81.7	180.0	455.0
Central Pacific	7.5	8.5	11.0	12.5	19.0	32.0
South Pacific	.9	1.3	1.7	1.9	3.5	4.2
U.S. total	212.4	264.7	405.5	356.0	591.2	1,215.0

[1] Estimates are for gross wastes without treatment. Assumed degrees of treatment are indicated in appendix tables.

D. Conversion of pollution loadings to oxygen demand.—The next step of this analysis requires that the reoxygenation capacity of the stream be expressed in terms of P.E. This can be accomplished by dividing the reoxygenation capacity by 0.25, the amount of oxygen required to completely reduce the organic oxygen demanding wastes of one population equivalent. The difference between this figure and the projected load of industrial and municipal wastes after treatment will indicate either the reoxygenation surplus available or the oxygen deficiency which must be compensated for, depending upon the quantities involved.

E. Estimating cost of treatment, for varying degrees of treatment.—The value of the reoxygenation capacity of a stream can be considered as roughly equal to the cost of equivalent biological waste treatment. The cost, on a unit basis, for the equivalent treatment varies with size of plant, but for each area studied one should be able to use an average value, derived from PHS studies made recently, of $3 per p.e.[12] For the purpose of these calculations, the cost was scaled from $2 per population equivalent (p.e.) at 60 percent b.o.d. removal prior to discharge to $6 at 95 percent b.o.d. removal. The values given are total annual treatment costs which include amortization of capital investment and operation and maintenance costs. It is realized that unit costs vary widely from basin to basin and that further refinement could be accomplished by using a representative figure for each basin. The PHS report to the Senate select committee expressed these unit costs on a per capita basis and included the cost of the collecting system. Because the figures given herein are all on a P.E. basis and because in many basins deductions from P.E. values have been made to allow for discharge to the sea or lakes, it was considered best to use the P.E. rather than the per capita basis and to delete the cost of the collecting system. RFF has excluded collection costs for the municipal portion, at an evaluated cost of $1.30 per capita. Accumulating these values, the basic cost figure used herein would then be approximately $5 per capita including collection, or 15 percent above the national average figure given in Committee Print No. 9.

Using the Ohio as an example, the municipal waste discharges in the basin in 1980 are estimated to be 8.52 P.E. in millions. The annual cost would be $8.52 \times 0.7/0.3 \times \$3 = \$60{,}000{,}000$. Here the 8.52 P.E. represents the 30 percent residual being discharged to the stream after 70 percent removal of b.o.d., the division by 0.3 brings this to the total produced, the multiplication by 0.7 brings it to the amount treated, and then times $3 per P.E. provides the total annual cost. For any other annual cost, one would use the appropriate percentages, 0.8/0.2 for 80 percent b.o.d. removal, etc., and scaled unit cost; $4 for 80 percent b.o.d. removal.

To arrive at the approximation of capital cost of the facilities required to remove 70 percent of the b.o.d., a population equivalent unit cost value of $75, derived from published plant costs data throughout the country, was used. Thus, the capital cost could be derived either by multiplying the treated p.e. $\left(8.52 \times \frac{0.7}{0.3}\right)$ by 75 or the annual cost $\left(8.52 \times \frac{0.7}{0.3} \times 3\right)$ by 25. The capital cost in

[12] Committee Print 9, of Senate Select Committee on National Water Resources (1960).

the Ohio would, thus, be $1,500 million. The capital cost figures for other percentage of treatment were scaled upward from $75 per p.e. for 70 percent removal to $100 per p.e. for 90 percent. Capital cost can be calculated by using the following factors; 30, 25, 22, and 20—for percentage treatments of 60, 70, 80, and 90, respectively. The 90-percent treatment value would thus amount to the p.e. $\left(8.52\times\frac{0.9}{0.1}\right)\times 100$ or the annual cost, $\left(8.52\times\frac{0.9}{0.1}\times 5\right)\times 20$. The latter multiplication factor is preferable because, should different annual costs be employed in different basins, it makes unnecessary the computation of unit capital costs by basin. The capital cost figures used were taken from published records, but are very general inasmuch as area, size, type, etc., affect costs markedly as well as degree of treatment. It is interesting to note that the annual cost is between 4 and 5 percent of the capital cost. The RFF studies have used 4½ percent.

The annual costs are presented, for different degrees of treatment, for all the regions, in tables 1 through 22 in the appendix.

F. Determination of the permissible pollution loading at a single point.—If it is desired to investigate the limits of one concentrated site with no subsequent pollution within the regenerative downstream reach, but with prior pollution already depressing the D.O. to 4 p.p.m. at the point of discharge, the allowable P.E. would be:

$$K_1L' = K_2D$$

$$L' = (K_2/K_1)\ D \text{ or } f \text{ times } D \text{ where } f = k_2/k_1 \quad (9)$$

$$\text{P.E.} = 8.3\times\frac{nQL}{3V}\times(f)\text{D}\times 4.0 \quad (10)$$

It can be seen from equation 10 that one large concentrated load in a particular reach rather than several incremental loads can be 10 times as large as the smaller incremental (continuous) loadings but this is only approximately 0.714 times the permissible total that the stream could handle on a continuous loading basis. This, of course, assumes that the stream has an opportunity to recover before it receives any additional discharge.

Another way to say this is that uniform loading of a stream will permit 1.4 times as much waste discharge as will concentrated loading. However, it is important to realize that actual pollution loadings on streams are in fact concentrated point loadings rather than the latter type of uniformly distributed loading. Thus, a realistic appraisal of the assimilative capacity of a river, based on this study, must take this fact into account, or a conservative approach would be to reduce the permissible loadings calculated by formula (8) by 40 percent.

In the case where there is no pollution prior to loading, no subsequent pollution before the receiving water has fully recovered, and an initial oxygen deficiency of zero, the allowable load is:

$$L''_a = Df^{(1/f-1)} \quad (11)$$

$$\text{P.E.} = 8.3\times\frac{nQL}{3V}\times(C_s-4)\times f^{(1/f-1)} \quad (12)$$

Under these conditions, for $f=2.0$, the stream could take twice the concentrated load indicated in the previous example. Though larger concentrated loadings can be assimilated by this method, more total waste can actually be still accommodated in a stream by continuous smaller loadings, however.

G. Results of the Application of the Technique.—Each basin has been analyzed for criterion 1, on the basis of formula (8), and the results are shown in tabular form in the appendix. These results assume that the pollution loading will be distributed along the entire reach of the stream in a fixed ratio of population equivalent to reoxygenation capacity such that the D.O. of the stream at no time will go below four parts per million (4 mg/l).

Under practical circumstances, it must be recognized that portions of a stream may be dedicated to use requiring that lower dissolved oxygen levels be permitted. This, of course, makes possible adjustment for higher dissolved oxygen levels in other parts of the basin. The blanket use of four parts per million is a simple premise which could be considered an upper limit to stream use for b.o.d. assimilation. An assumption that for some reasonable portion of the stream, the D.O. will be allowed to go below four p.p.m. makes possible, of course, a decrease in the dilution requirements. This is a matter of policy on any particular stream, however.

The specific calculation procedures employed in the development of the dilution requirements under criterion 1 are illustrated in the following example, using the Ohio River Basin: The estimated population equivalents of municipal waste discharges in the basin for 1980, based on 70-percent treatment, and for year 2000, based on 80-percent treatment, are, from table III, 8.5 million and 7.9 million, respectively. These values were divided by 3 and 2, respectively, to determine the 90-percent treatment values. The other values were calculated in a similar way, resulting, for example, in the following data for the year 1980.

Percentage treatment	P.E. load in millions	
	Municipal	Industrial
50		8.0
60		6.2
70	8.5	4.6
80	5.7	3.2
90	2.8	1.6
95	1.4	.8
97.5	.7	.4

The industrial P.E. loadings, which were given in terms of total amounts produced, were reduced to allow for the appropriate degree of treatment and recorded. Thus, for the Ohio, the total load in 1980 is, from table V, 15.6 million P.E., which, with 50 percent treatment, becomes 8.

Costs were determined in the manner previously described, using an appropriate figure of $2 for 60 percent, $3 for 70 percent, $4 for 80 percent, $5 for 90 percent, and $6 for 95 percent treatment. Thus, in determining the cost for 70 percent treatment, the appropriate population equivalent value was divided by 0.3, multiplied by 0.7 and 3; in other words multiplied by a factor of 7.

The dilution requirement was determined by a regrouping of formula (7) such that:

$$Q=\left(\frac{P.E.}{Dk_2nL/V}\right)39{,}300 \qquad (13)$$

In this case, at 70 percent treatment, for example, the annual cost for municipal wastes would be $8.5\times0.7/0.3\times3=\$60{,}000{,}000$ and the dilution requirement $\frac{8.5\times24\times39{,}300}{4.4\times0.3\times7.0\times100}=8{,}550$ mil. g.d.

k_2 from table I was 0.3 and $D=C_s-4$ mg./l$=8.4-4=4.4$. n was previously calculated as 7.0, $L=100$ miles and $V=24$ m.p.d. The values for other levels of treatment are tabulated as follows:

Percent	Annual cost in millions		Dilution (mil.g.d.)	
	Municipal	Industrial	Municipal	Industrial
50		15.5		8,300
60		18.6		6,000
70	60	32.5	8,550	4,300
80	80	40.6	6,050	3,270
90	126	70.0	3,020	1,680
95	147	84.0	1,510	825
97.5	161	90.0	755	410

It can readily be seen from equation (13) that alteration of the dissolved oxygen level (D_s) will affect only the value of D in the equation: consequently for any other assumed or proposed value of D, the new dilution figure is secured simply by multiplying Q by D_s/D_x where D_x represents the desired value for D other than (D_s). The tributaries and main stem can be separately computed by using a ratio $D_sn/D_xn'=1$, where $n'=1$ for the tributaries only and $n'=n-1$ for the main stem.

If it is desired to compute the capital costs, the annual cost values should be multiplied by 30, 25, 22, and 20 for treatment levels of 60, 70, 80 and 90 percent, respectively.

Criterion No. 2. Plant nutrients

The second criterion, which is based on the objective of preventing undesirable algal growths downstream from the points of waste discharge, becomes important as the ratio of waste loadings to receiving stream flow decreases with increasing degree of treatment, since, with higher levels of treatment, less reliance is placed on the receiving water itself as a disposal device for organic pollution. Ideally, the biological forces utilizing carbonaceous material (b.o.d.) require nitrogen and phosphorus in b.o.d./N and b.o.d./P ratios of 16:1 and 100:1 respectively.[13] At a b.o.d./N ratio greater than 16:1 no nitrification occurs, but nitrification increases at ratios less than 16:1. Normal raw sewage usually has ample N and P to sustain the biological forces required to reduce the b.o.d., with the nitrogen content averaging 25–30 mg/l.

[13] Helmers, Frame, Greenberg, and Sawyer, SIW 23, 884 (1951).

The bacterial utilization of nitrogen and phosphorus in the receiving water, in the process of reducing b.o.d., can be formulated in terms of equation (8) by noting that the nitrogen assimilative capacity would be equal to the oxygen regeneration times the ratio of N/b.o.d. The N/b.o.d. uptake ratio of "Zooglea ramigera," or sewage slime, is from 1:10 to 1:15. Using 1:10 to compensate for adjustment to ultimate conditions and to conform to general experience, which indicates that the b.o.d./N ratio for normal sewage of a strength of 200 mg/l of b.o.d. is usually 10:1, formula (14) can now be written as formula (15).

$$\text{lbs. of nitrogen/day} = 2.3k_2 \times \frac{Q}{3} \times n\frac{L}{V} \times 8.3 \times D \times \frac{N}{\text{b.o.d.}} \qquad (14)$$

$$\text{lbs. of nitrogen/day} = \text{lbs. of reoxygenation} \times \frac{1}{10} \qquad (15)$$

As the b.o.d. is reduced, by treatment, for example, of 90 percent, to 20 mg/l, the b.o.d./N ratio that was 10:1 in the raw sewage now becomes of the order of 2:1. The receiving water is now no longer being used to dispose of b.o.d., but, rather primarily for disposing of nitrogen and phosphorus. This is accomplished by algae, which utilize the nitrogen and phosphorus as food.

The upper level of permissible concentration of available nitrogen, if algal troubles are to be prevented, appears to be about 1.0 mg/l. This provides ample reserve above the 0.3 mg/l level generally considered acceptable and still allow for nitrogen already present in the stream. All waste effluent nitrogen is conceivably available for algal production. However, sewage treatment does reduce the nitrogen discharge to, say, 24 mg/l on the average for primary treatment (35-percent b.o.d. reduction) and to 7 mg/l for complete treatment (the 90-percent level). Using these criteria, it is possible to formulate empirically the nitrogen discharge in terms of treatment levels. From this, the nitrogen load, in terms of the total effluent nitrogen, becomes:

$$\text{lbs. of nitrogen per day} = \left[(90-T)\frac{17}{55}+7\right]8.3W \qquad (16)$$

where W is the municipal water intake, used here as a measure of sewage outflow and T is percentage of sewage treatment requirement.

Thus, as the b.o.d. load decreases, the total nitrogen load obviously also decreases. However, in the past, the dilution ratio has been used as the basis for providing for b.o.d. reduction in streams as well as for prevention of algal growth. The general criteria used has been to provide dilution for raw sewage at a point source as follows, based on providing an adequate dissolved oxygen level:

	[c.f.s./1,000 p.e.
Swift streams	2–3
Sluggish streams	10
Average value	6

For domestic sewage this is approximately a volume ratio of 40:1, stream flow to raw sewage flow. Generally, these dilution ratio requirements can be reduced for treatment, suggesting 1.2 c.f.s./1,000 p.e., or a ratio of 8:1 for 80-percent reduction of b.o.d. For 90-percent reduction the ratio would be 4:1, and 95-percent it would be 2:1. To say this another way, even with 95-percent sewage treatment, using this criterion, three volumes of streamflow are required to allow one volume of upstream withdrawal for municipal water supply (assuming that ensuing sewage discharge equals the withdrawal) in order to avoid objectionable algal growths below the point of discharge of the return flow. This is on a point-by-point basis, but not in the aggregate, because dilution water does become available again after the algae has removed the nitrogen and phosphorus. However, the latter statement is still not altogether true on a continuous basis for the whole length of the river, because N and P can become once again available for plant growth upon the death and decomposition of the algae. This cyclical effect can occur several times in the total length of a stream. Also, all nitrogen eventually becomes available in time in a receiving water. Thus, the foregoing dilution values are considered conservative.

Using the Ohio River as an illustration, the dilution requirement, derived by means of equation 13, amounts to 8,400 mil. g.d. at the 70-percent treatment level for a discharged raw load equivalent to 8.5 P.E. Using the dilution ratio mentioned above, the dilution requirement would be equal to the P.E. value times the ratio or 8.5 x 4,000 (6 c.f.s./1,000 P.E. level in terms of mil. g.d./

P.E.), or 34,000 mil. g.d. This is roughly 4 times the requirement by equation 13 and dramatically illustrates the decided advantage of using a formula such as this so as to provide credit to a river system for recovery and reuse as it flows from headwater to mouth. It should be pointed out, however, that there is a high degree of uncertainty as to what dissolved oxygen level these empirical dilution ratios will maintain and that this illustration is based on the assumption that the total basin P.E. load would be concentrated at a single point. If a series of concentrated loadings were used, spaced to permit recovery of the river before the next load is added, the dilution requirements could be reduced accordingly and compared to the reduced available streamflow at the points of discharge spaced progressively upstream. This situation is analogous to using equation 10, or 12, rather than 7, and as has already been noted requires approximately 40 to 60 percent reduction in allowable P.E. or corresponding increase in dilution requirements.

A dilution criterion for nitrogen could also be developed by considering 1.0 mg/l as the upper limit of nitrogen concentration required to prevent algal pollution and then computing the necessary dilution to reduce the sewage effluent concentration accordingly. This has been done in table VI. Note that by straight dilution, the amounts required for nitrogen alone are always higher than the rule-of-thumb dilutions. Thus, to be realistic, it is necessary to apply a factor to account for the assimilation of nitrogen by the stream environment.

The nitrogen uptake rate for algae is at a rate approximately one-tenth of that of the biological slimes.[14] Therefore, the assimilation of nitrogen in the stream by algae could be formulated as follows:

$$\text{lbs. of nitrogen/day} = 2.3 \times k_4 \times 8.3 \times \frac{QnL}{3V} \times 1 \qquad (17)$$

where k_4 is the algal uptake rate of nitrogen and $k_4 = \frac{k_1}{10}$

[14] This analysis is based on nitrogen rather than phosphorus because the allowable N/P ratio is approximately 6.1 and the actual occurrence ratio of phosphorus in sewage effluent is considerably less than 6.1. Also, this analysis assumes that the nitrogen load is primarily from domestic sources. This is the reason for using the population to determine the load. Studies at the University of Oklahoma under an NIH grant indicate the uptake rate of P^{32} by algae to be one tenth of "Zooglea ramigera."

The nitrogen in the waste effluent (equation 16) must be equal to that used by the biological forces in reducing the residual b.o.d. (equation 14) plus that used by the algae (equation 17) plus that remaining in the stream; this is shown in equation (18) as follows:

$$\frac{Q}{W} = \frac{(90 - T)\frac{17}{55} + 7}{\frac{2.3nL}{30\,v}(k_2 D + k_1) + 1} \qquad (18)$$

These values are also shown in table VI and in figure 1. The ratio of Q/W will vary with the basin and in particular, with the values of T, and nL/V. Each of these must be calculated.

It is also believed that the degree of treatment of the waste water effluent can be used to predict the location of algal development. Streams receiving highly treated effluent tend to develop algal pollution immediately below the point of discharge, while for poorly treated wastes algal growths will develop further downstream. Using a level of nitrification corresponding to the degree of reduction in b.o.d. by treatment, the dilution water requirements can easily be determined. Equation (18) represents the latter case. An equation can be developed, however, using the available nitrogen as:

$$\text{lbs of nitrogen} = \left(\frac{T - 30}{8.1}\right) 8.3 \times W \times 0.8 \qquad (16a)$$

This would result in

$$\frac{Q}{W} = \frac{\frac{T - 30}{8.1}}{\frac{2.3nL}{30\,V}(k_2 D + k_1) + 1} \qquad (18a)$$

Using $n = 1$, generalized values are computed from equation (16a) and are also shown in table VI for both well treated and poorly treated effluent conditions. These calculations resulted in larger values than were the result of using equations (16) and (18).

The illustration for the Ohio, for municipal waste treatment at a level of 70 percent simply applies the computed dilution ratios to a sewage effluent of 2,374 mil. g.d., the resulting dilution volumes being either 8,100 or 6,800 mil. g.d. depending upon whether formula (18a) or (18) was used. The industrial values were computed from the waste

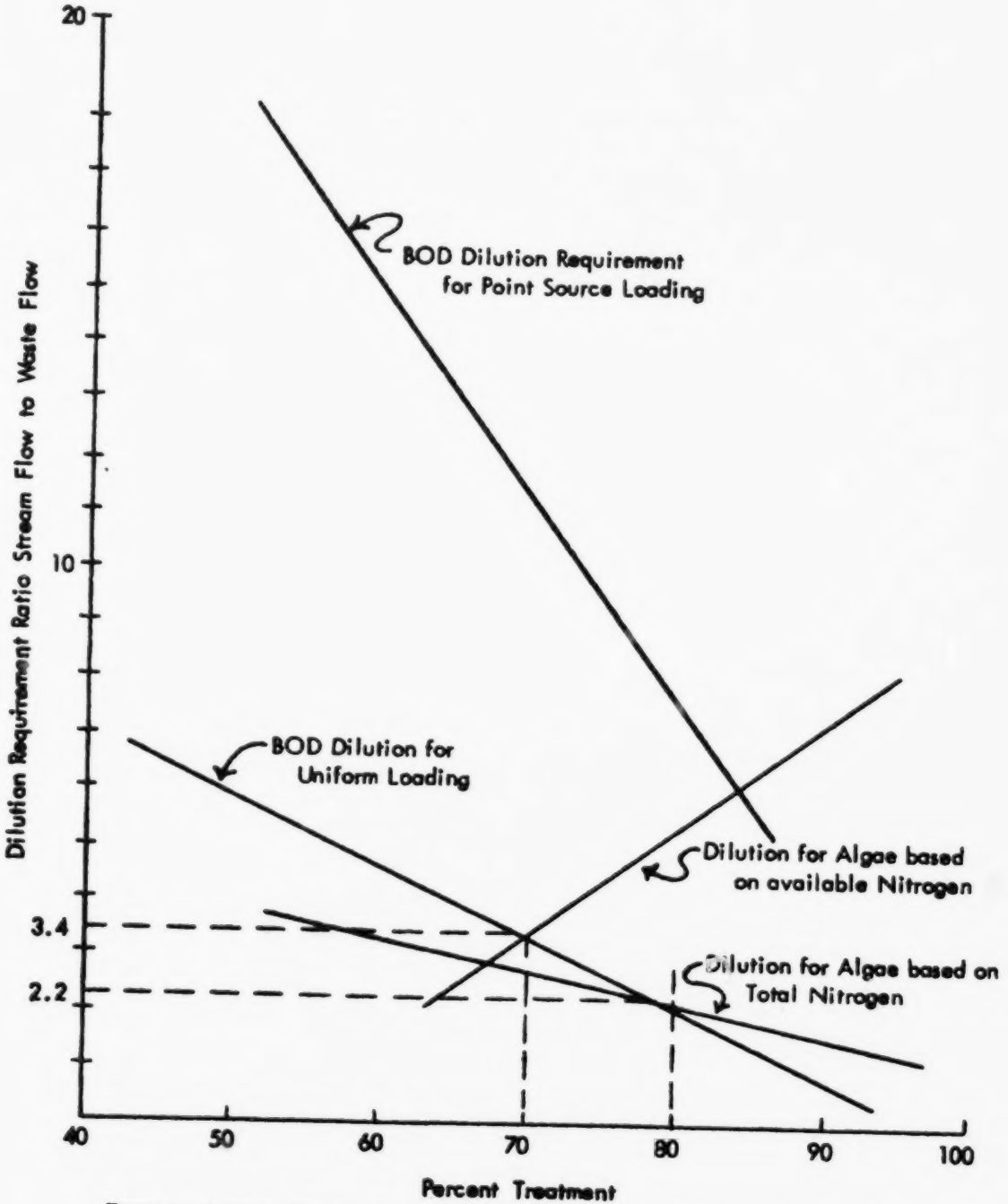

FIGURE 1.—MINIMUM DILUTION VALUES FOR MAINTENANCE OF 4 P.P.M. DO IN THE OHIO RIVER.

flows furnished by RFF. Required dilution would be 3.4×1974, or 6,700 mil. g.d. Industrial wastes involved are all assumed to be organic; the concentration of nitrogen is not known but is assumed to be similar to that for municipal wastes.

Inspection of the illustrative Ohio Basin data indicates a break point between b.o.d. dilution and algal dilution at 70 percent treatment under least favorable conditions, and 80 percent where the stream is assumed to assimilate considerable nitrogen. This is seen graphically in figure 1. The break point is the lowest allowable dilution ratio, taking into account the dilution needs for both b.o.d. and nitrogen. For treatment levels below the break point, dilution for b.o.d. is controlling, but for higher degrees of treatment, dilution for algal control dominates. A degree of treatment corresponding to the break point should, therefore, be sought, as representing the most desirable level.

If the effective dilution is based on available nitrogen, the ratio is considerably higher than if it were based on total nitrogen, because in the first case the stream is assumed to immediately use the material, that is, within one day, while in the second case the entire reach of the stream is involved. Actually, if credit is given to the multiple use or reuse of nitrogen and phosphorus, the n value used could be considerably reduced and the results of the equation based on total nitrogen would be more in keeping with those of the equation representing only available nitrogen. The higher or more conservative values were used in the general calculations found in the appendix.

Criterion No. 3. Persistent chemicals

The third and final criterion is based on the ability of a receiving water to tolerate a non-assimilated or only slightly assimilated type of waste, and is needed to determine the amount of dilution water required to keep these wastes to tolerable levels. This is perhaps the most difficult of the criteria to develop because of the great variety of chemicals found in waste waters. Organic chemicals appear to be the best or most representative criterion for this class of wastes, for all basins except the Arkansas-Red River Basins, and some of the other western streams which are heavily used for irrigation, where brine is by far the best criterion. With either type of chemical, however, it is necessary only to determine the accumulated load and then to determine dilution required to maintain a constant ratio of brine or organic chemical load to minimum flow, on a point by point basis. For example, in the Arkansas-Red Basins, this ratio should be such that $\frac{\text{lbs. of brine per day}}{\text{flow (mil.g.d.) x 8.3}}$ is less than 250 mg/l (or 250 p.p.m.). (See Table VII.)

In this table, it will be noted that one has a choice of either providing dilution as noted, or of reducing the concentration in the stream as is now being proposed with respect to chloride concentrations in the Arkansas-Red Basins. As to the organic chemicals in general, the chloroform extractables appear to be the best index[15] for industrial pollution, using an upper limit of 300 mg/l 1000 or 300 parts per billion (p.p.b.).

For purposes of this analysis the permissible loadings of organic chemicals will be taken at 300 p.p.b. at any point, with organic chemical production as a base indicator. Projected concentrations of these chemical wastes, in parts per billion, are computed by applying the ratio of projected production to present production in the industry to the present concentrations of these chemicals in the river in each case. The dilution water index is then computed by dividing the result by 300 to get the required increase over present flows. The industrial production values were furnished by the Department of Commerce and the chemical concentrations in the river basins were furnished by the PHS, where known,

[15] Practical Considerations in Prescribing the Chemical Quality of Water Suitable for Drinking Water, M. B. Ettinger, Advisory Committee on Revision of Drinking Water Standards, USPHS, March 1959.

TABLE VII.—*B.o.d.-nitrogen dilution relationships for the Ohio River*

Percentage reduction of b.o.d.	Dilution, rule-of-thumb ratio, to maintain adequate dissolved oxygen in river	Dilution required by formula (13) (ratio)	Total nitrogen in the treated waste effluent (mg/l)	Dilution to reduce nitrogen to 1.0 mg/l level (ratio)	B.o.d./N ratios	Q/W total nitrogen dilution ratio equation (18)	Q/W available nitrogen dilution ratio equation (18a) (ratio)
30	28:1	.....	25.6/1	25.6/1	14/1	.....	.....
40	24:1	.....	22.5/1	22.5/1	12/1	.....	.....
50	20/1	6.7/1	19.4/1	19.4/1	10/1	.....	.....
60	16/1	5.4/1	16.3/1	16.3/1	8/1	.....	.....
70	12/1	4.0/1	13.2/1	13.2/1	6/1	2.9/1	3.4/1
80	8/1	2.3/1	10.1/1	10.1/1	4/1	2.2/1	4.1/1
90	4/1	1.1/1	7.0/1	7.0/1	2/1	1.5/1	5.0/1
95	2/1	.7/1	5.5/1	5.5/1	1/1	1.2/1	5.5/1

and incorporated in table VIII. The computed dilution requirements are presented in this table.

In general, this analysis indicates that dilution requirements for the persistent chemicals are lower than those for the first two criteria, namely, b.o.d. and plant nutrients, with the possible exception of the southeast region. Thus, they do not appear to be controlling criteria in determining dilution water and are, therefore, not included in the appendix tabulations.

TABLE VIII.—*Estimates of salt in Arkansas and Red River*[1] *systems at present time and after successful control*

Location	Salt as Cl, weighted average without implementation		Salt as Cl, weighted average with implementation		
	Tons per day	P.p.m.	Tons per day	P.p.m.	Index[2]
Canadian River at Eufaula	3,000	300	1,000	100	1.2
Arkansas River at Keystone Reservoir	10,000	600	4,000	240	2.0
Arkansas River at Arkansas State line	13,000	250	5,060	96	.....
Red River at Lake Texoma	3,400	300	1,100	97	1.2
Red River at Louisiana State line	3,500	100	1,200	34	.....

ASSUMPTIONS

1. 50 to 60 percent of natural pollution should be controlled.
2. 90 to 95 percent of manmade pollution should be controlled.
3. Approximately 30 to 40 percent of all chloride contribution is manmade.
4. Approximately 60 to 70 percent of all chloride contribution is natural.

[1] Data furnished by regional office of PHS.
[2] Ratio of streamflow to 1960 flow necessary to reduce concentration to 250 mg/l of Cl⁻.

TABLE IX.—*Index of increased flow required to dilute projected chemical wastes, by water resource region (based on original and projected chemical production*[1] *and corresponding concentration of chloroform extractables (p.p.b.))*

Basin	1959	1980	Index	2000	Index[2]
New England	237	548	.....	1,060	.....
	(150)	(340)	1.16	(710)	2.36
Delaware and Hudson	1,630	3,820	.....	7,710	.....
	(110)	(258)	.....	(322)	1.73
Chesapeake	372	1,630	.....	2,400	.....
	(0)	(170)	.....	(386)	1.32
Eastern Great Lakes	630	1,570	.....	3,370	.....
	(40)	(100)	.....	(213)	.....
Ohio	973	2,420	.....	5,200	.....
	(124)	(310)	1.02	(650)	2.16
Tennessee	229	530	.....	1,070	.....
	(57)	(132)	.....	(266)	.....
Southeast	368	1,400	.....	4,400	.....
	(200)	(810)	2.7	(1,800)	6.0
Western Great Lakes	655	1,630	.....	3,500	.....
	(30)	(74)	.....	(160)	.....
Upper Mississippi	372	924	.....	1,980	.....
	(85)	(212)	.....	(455)	1.51
Lower Mississippi	213	814	.....	2,380	.....
	(40)	(153)	.....	(450)	1.50
Upper Missouri	90	233	.....	518	.....
	(40)	(104)	.....	(230)	.....
Lower Missouri	14	30	.....	53	.....
	(40)	(86)	.....	(152)	.....
Upper AWR	57	213	.....	627	.....
	(100)	(372)	1.24	(1,100)	3.75
Lower AWR	102	217	.....	377	.....
	(60)	(128)	.....	(220)	.....
Western Gulf	.....	.....	.....	.....	.....
	(60)	.....	.....	.....	.....
Rio Grande-Pecos	.....	.....	.....	.....	.....
	(60)	.....	.....	.....	.....
Central Pacific	81	140	.....	166	.....
Southern Pacific	99	256	.....	567	.....
Pacific Northwest	44	115	.....	255	.....
	(50)	(130)	.....	(290)	.....
Cumberland	.....	.....	.....	.....	.....
Colorado	.....	.....	.....	.....	.....
Great Basin	.....	.....	.....	.....	.....

[1] In terms of dollar value added (1954).
[2] The ratio of required riverflow to 1959 riverflow for reduction of concentration level to 300 p.p.b.
Blank spaces indicate areas where concentrations are below level of concern.

CONCLUSIONS

Three techniques for dealing with different kinds of water pollutants have been described. The limiting one in each instance should be the key to limits on future river development. In general, the first, oxygen degradation, will become increasingly less important, as degree of waste treatment increases, giving way to the second and perhaps eventually to the third.

These techniques are intended for general planning purposes only and are limited in that sense.

The basic data employed was available from various agencies, but only in certain forms. The fact that the P.E. values were available only basinwide forced the use of basinwide k_2 values. No proven values were available, consequently averages were used as estimates. On the Ohio, for example, the Cincinnati and Pittsburgh pools are at present the critical pollution points and there the k_2 values are of the order of 0.12 against the average used of 0.30 for the basin as a whole. The same comments can be made about the velocity measures. Consequently, the tabular projected b.o.d. loading and computed b.o.d. and algae dilutions found in the appendix are subject to errors inherent in the basic data.

In some circumstances the basic data employed combined to make one basin appear unreasonably better than another, yet until more knowledge is gained on actual river preference little else can be done. To illustrate, consider the results in the appendix of the technique applied to the Ohio, Tennessee, and the Cumberland Basins. Here the Ohio literally looks too good in that the regional requirement for b.o.d. dilution uses up less than one-third of the average year 2000 flow, whereas the Cumberland and Tennessee regions use up more than three-fourths of their flow at roughly the same level of waste treatment.

The b.o.d. dilution requirement was computed from equation (13) where:

$$Q=\frac{PE}{k_2 D \frac{nL}{V}} 39{,}300 \qquad (13)$$

Now consider only the effect of the selection of the basic data values k_2 and $\frac{nL}{V}$ on these dilution requirements. $\frac{nL}{V}$ is, as will be recalled, retention time, t, and with PE and D held constant equation (13) can be written as:

$$Q=\frac{C}{k_2 t} \qquad (19)$$

For the three basins under consideration the values used are as follows:

Basin	k_2		Basin length		Velocity		Relative t	Relative $k_2 t$
	Absolute	Relative[1]	Absolute	Relative[1]	Absolute	Relative		
Ohio	0.31	1.00	920	1.00	1.0	1.0	1.00	1.00
Tennessee	.16	.51	700	.76	1.5	1.5	.51	.26
Cumberland	.31	1.00	320	.35	1.5	1.5	.23	.23

[1] Relative to the Ohio.

From this it can be seen that for similar levels of sewage treatment, the Tennessee, with a velocity of 1.5 times that of the Ohio, and with only 76 percent of the Ohio length, will be subject to reaeration of 51 percent as much as the Ohio. Furthermore, its k_2 is one-half of the k_2 of the Ohio, reducing its reaeration capacity by one-half, thus a total reduction of 26 percent. By the same reasoning, the Cumberland has an aeration time of only 23 percent of that of the Ohio. With this in mind it is certainly not unreasonable to expect a greater portion of the flow to be used for oxygen generation in the Cumberland and Tennessee Rivers. Thus, $k_2 t$ for the Cumberland and Tennessee for the same values of k_2 and t of the Ohio would require only one-fourth of the present dilution requirement and one-third of the total flow.

The assumption used and the resulting dilutions need to be evaluated in the light of actual stream performance. This has been done only, and in a cursory fashion, on the Ohio. The primary problem is that basin stream analyses just are not available and that computed values will necessarily need to be evaluated against smaller subbasins wherein data are available. This is planned under USPHS auspices.

For the reasons stated, then, the basic data, the P.E. values for years 1980 and 2000, and the projected water requirements for the same period, which are tabulated in the appendix, following, are certainly only "talking figures."

APPENDIX

The tables show projected b.o.d. loadings and computed b.o.d. and algae dilution requirements in relation to degree of treatment, for maintenance of 4 p.p.m. of dissolved oxygen in stream, for each water resource region, for projected medium rate of population growth.

TABLE 1.—*Basin data sheet for New England region*

Basic data: k_2, .28; temp., 70; C_s, 9.14 p.p.m.; D_a, 5.14 p.p.m.; N, 1.0. Water required, 1980 and 2000, in mil. g.d.: 738 and 1,011. Waste water discharge, in mil. g.d.: 825 municipal and 1,849 industrial.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50		9.7		$15.8	(19,500	95,900		
60		7.9		23.7	(19,568)	77,400		
70	2.0	5.8	$14.0	40.5	19,500	57,200	2,500	2,800
80	1.33	3.9	21.3	62.4	13,000	37,500	3,020	2,370
90	.67	1.9	29.7	85.5	[2] 6,600	18,800	3,680	4,120
95	.34	1.0	36.8	108.0	3,300	9,400	4,050	4,530
97.5	.17	.5	38.0	112.0	1,600	4,700	4,240	4,740
ESTIMATES FOR THE YEAR 2000								
50		21.5		$43.0	(16,400)	212,000		
60		17.2		51.6	(16,400)	170,700		
70		12.9		90.5	(16,400)	127,200	3,740	6,300
80	1.65	8.6	$26.4	138.0	16,400	82,700	4,520	7,600
90	.82	4.3	36.9	194.0	8,100	42,600	5,050	9,250
95	.41	2.2	44.3	238.0	4,000	21,300	6,050	10,200
97.5	.20	1.1	44.8	246.0	2,000	10,700	6,320	10,600

TABLE 2.—*Basin data sheet for Delaware and Hudson region*

Basic data: k_2, 0.36; temp., 70; C_s, 9.14 p.p.m.; D_a, 5.14 p.p.m.; N, 2.0. Water required, 1980 and 2000, in mil. g.d. 1,570 and 2,220. Waste water discharge, in mil. g.d. 510 and 930.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50		5.5		$11.0	(21,400)	21,900		
60		4.4		13.2	(21,400)	17,800		
70	5.3	3.3	$37.0	23.1	21,400	13,400	5,340	1,740
80	3.5	2.2	56.0	35.2	14,100	8,200	6,440	2,100
90	1.8	1.1	81.0	49.5	7,300	4,400	7,850	2,550
95	.90	.55	97.3	59.4	3,700	2,200	8,640	2,800
97.5	.45	.28	101.0	62.7	1,800	1,100	9,030	2,940
ESTIMATES FOR THE YEAR 2000								
50		9.0		$18.0	(19,400)	36,400		
60		7.2		21.6	(19,400)	28,800		
70		5.4		37.8	(19,400)	21,900	7,550	3,160
80	4.8	3.6	$77.0	57.5	19,400	14,600	9,100	3,800
90	2.4	1.8	108.0	81.0	9,680	7,040	11,100	4,650
95	1.2	.9	130.0	97.3	4,900	3,500	12,200	5,110
97.5	.6	.45	134.5	101.0	2,400	1,800	12,750	5,350

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

Table 3.—Basin data sheet for Chesapeake Bay region

Basic data: k_2, 0.22; temp., 73; C_s, 8.72 p.p.m.; D_4, 4.72 p.p.m.; N, 2.5. Water required, 1980 and 2000, in mil. g.d.: 1,100 and 1,670. Waste water discharge, in mil. g.d.: 1,300 and 2,660.

[Pollution loads, treatment cost, b.o.d. and algae dilutions]

ESTIMATES FOR THE YEAR 1980

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
50		12.0		$24.0	(23,500)	72,900		
60		9.6		28.8	(23,500)	57,000		
70	3.91	7.2	$27.3	50.5	23,500	43,800	3,740	4,400
80	2.6	4.8	41.6	76.9	15,800	28,900	4,500	5,330
90	1.3	2.4	58.6	108.0	7,900	14,600	5,500	6,500
95	.7	1.2	75.6	129.5	3,900	7,300	6,050	7,150
97.5	.35	.6	78.4	134.5	2,000	3,600	6,320	7,470

ESTIMATES FOR THE YEAR 2000

50		19.5		$40.0	(24,300)	118,500		
60		15.6		46.8	(24,300)	95,000		
70		11.7		82.0	(24,300)	70,600	5,700	9,050
80	4.6	7.8	$64.0	125.0	24,300	48,400	6,850	10,900
90	2.0	3.9	90.0	175.0	12,100	23,000	8,350	13,300
95	1.0	2.0	108.0	216.0	6,000	11,500	9,200	14,620
97.5	.5	1.0	112.0	224.0	3,000	5,800	9,600	15,300

TABLE 4.—*Basin data sheet for southeast region*

Basic data: k_2, 0.24; temp., 83; C_s, 7.8 p.p.m.; D_4, 3.8 p.p.m.; N, 1.5. Water required, 1980 and 2000, in mil. g.d.: 1,520 and 2,330. Waste water discharge, in mil. g.d.: 1,880 and 4,250.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

ESTIMATES FOR THE YEAR 1980

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
50		6.0		$12.0	(31,300)	36,800		
60		4.8		14.5	(31,300)	24,700		
70	6.1	3.6	$42.8	25.0	31,300	18,500	5,170	6,400
80	4.0	2.4	64.0	37.4	20,700	12,300	6,240	7,700
90	2.0	1.2	90.0	54.0	10,300	6,200	7,600	9,400
95	1.0	.6	108.0	64.9	5,200	3,100	8,350	10,350
97.5	.5	.3	112.0	69.3	2,600	1,600	8,750	10,810

ESTIMATES FOR THE YEAR 2000

50		10.5		$21.0	(34,200)	54,300		
60		8.4		25.2	(34,200)	42,500		
70		6.3		44.1	(34,200)	32,600	7,900	14,100
80	6.6	4.2	$111.6	67.2	34,200	21,500	9,550	17,000
90	3.3	2.1	148.0	94.5	17,200	10,600	11,650	20,700
95	1.6	1.0	172.9	108.0	8,600	5,300	12,800	22,800
97.5	.8	.5	179.3	112.0	4,500	2,600	13,400	25,000

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 5.—*Basin data sheet for Western Great Lakes Region*

Basic data: k_2, 0.2; temp., 70; C_s, 9.1 p.p.m.; D_t, 5.1 p.p.m.; N, 1.7. Water required, 1980 and 2000, in mil. g.d.: 3,360 and 4,593. Waste water discharge, in mil. g.d.: 3,141 and 5,847.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50		7.9		$18		128,300		
60		6.3		19		101,300		
70	3.8	4.7	$26	33	60,800	76,500	7,500	7,100
80	2.3	3.2	41	50	40,500	51,000	9,000	8,600
90	1.3	1.6	57	71	20,300	25,500	11,300	10,500
95	.6	.8	68	85	10,100	12,800	12,400	11,600
97.5	.3	.4	71	89	5,250	6,400	13,000	12,100
ESTIMATES FOR THE YEAR 2000								
50		6.7		$13		108,600		
60		5.4		16		87,600		
70		4.0		28		64,800	8,400	10,600
80	1.9	2.7	$31	43	31,800	44,400	10,200	12,800
90	1.0	1.3	44	61	15,600	22,200	12,300	15,000
95	.5	.7	55	73	7,800	11,100	13,600	17,200
97.5	.2	.4	60	75	3,900	5,400	14,200	17,900

TABLE 6.—*Basin data sheet for Eastern Great Lakes region*

Basic data: k_2, 0.27; temp., 68; C_s, 9.2 p.p.m.; D_t, 5.2 p.p.m.; N, 2.0. Water required, 1980 and 2000, in mil. g.d.: 2,763 and 4,053. Waste water discharge, in mil. g.d.: 2,096 and 3,797.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50		6.5		$13.0	(38,200)	64,700		
60		5.2		15.6	(38,200)	51,900		
70	3.8	3.8	$26.5	26.5	38,200	38,200	5,300	4,000
80	2.6	2.6	41.5	41.5	26,000	27,000	6,050	4,800
90	1.3	1.3	58.0	58.0	12,900	12,900	7,200	5,500
95	.65	.65	70.3	70.3	6,500	6,500	7,930	6,050
97.5	.33	.33	74.0	74.0	3,200	3,200	8,280	6,330
ESTIMATES FOR THE YEAR 2000								
50		16.5		$33.0	(35,900)	163,200		
60		13.2		40.0	(35,900)	131,400		
70		9.9		69.0	(35,900)	98,600	7,300	6,700
80	3.6	6.6	$58.0	106.0	35,900	65,700	8,600	8,200
90	1.8	3.3	81.0	148.0	18,000	33,900	10,600	10,000
95	.9	1.7	97.2	183.0	9,000	17,000	11,670	11,000
97.5	.45	.9	101.0	202.0	4,500	8,500	12,200	11,500

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 7.—*Basin data sheet for Ohio River Region*

Basic data: k_2, 0.3; temp., 75; C_s, 8.4 p.p.m.; D_t, 4.4 p.p.m.; N, 7.0. Water required, 1980 and 2000, in mil. g.d.: 2,374 and 3,471. Waste water discharge, in mil. g.d.: 1,974 and 3,335.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50	----------	7.75	----------	$15.5	(9,000)	8,200	----------	----------
60	----------	6.20	----------	18.6	(9,000)	6,600	----------	----------
70	8.52	4.65	$60	32.5	9,000	5,000	8,100	6,700
80	5.68	3.10	89	49.6	6,000	3,300	9,900	8,100
90	2.84	1.55	128	70 0	3,000	1,700	11,800	9,850
95	1.42	.8	153	86.4	1,500	800	13,000	10,750
97.5	.71	.4	159	89.7	800	400	13,600	11,350
ESTIMATES FOR THE YEAR 2000								
50	----------	19.75	----------	$39.5	(8,400)	21,000	----------	----------
60	----------	15.80	----------	47.5	(8,400)	16,700	----------	----------
70	----------	11.85	----------	83.	(8,400)	12,500	11,800	11,400
80	7.9	7.90	$127	127.	8,400	8,400	14,200	13,700
90	3.95	3.95	175	175.	4,200	4,200	17,400	16,700
95	1.98	1.98	214	214.	2,100	2,100	19,150	18,400
97.5	.99	.99	222	222.	1,000	1,000	20,000	19,200

TABLE 8.—*Basin data sheet for Cumberland River region*

Basic data: k_2, 0.31; temp., 73; C_s, 8.72 p.p.m.; D_t, 4.72 p.p.m.; N, 2.0. Water required, 1980 and 2000 in mil. g.d.: 119 and 163. Waste water discharge in mil. g.d.: 223 and 515.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50	----------	1.45	----------	$2.9	(1,900)	7,000	----------	----------
60	----------	1.16	----------	3.5	(1,900)	5,600	----------	----------
70	0.40	.87	$2.8	6.1	1,900	4,200	405	750
80	.27	.58	4.3	9.3	1,300	2,800	490	915
90	.13	.29	5.8	13.0	600	1,400	595	1,120
95	.07	.15	7.5	16.2	300	700	655	1,230
97.5	.04	.08	9.0	18.0	200	300	685	1,290
ESTIMATES FOR THE YEAR 2000								
50	----------	2.80	----------	$5.6	(1,400)	13,600	----------	----------
60	----------	2.24	----------	6.7	(1,400)	10,900	----------	----------
70	----------	1.68	----------	11.7	(1,400)	7,700	555	1,750
80	0.30	1.12	$4.8	18.0	1,400	5,500	670	2,110
90	.15	.56	6.8	25.2	700	2,700	815	2,570
95	.08	.28	8.6	30.2	400	1,400	897	2,820
97.5	.04	.14	9.0	31.4	200	700	938	2,960

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 9.—*Basin data sheet for Tennessee River region*

Basic data: k_2, 0.16; temp., 78; C_s, 8.0 p.p.m.; D_4, 4 p.p.m.; N, 3.0. Water required, 1980 and 2000, in mil. g.d.: 311 and 441. Waste water discharge, in mil. g.d.: 386 and 937.

[Pollution loads, treatment cost, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50	----------	3.20	----------	$6.4	(5,900)	24,000	----------	----------
60	----------	2.56	----------	7.8	(5,900)	18,000	----------	----------
70	0.90	1.92	$6.3	13.5	5,900	13,900	1,050	1,320
80	.60	1.28	9.6	20.5	4,400	9,500	1,270	1,580
90	.30	.64	13.5	28.8	2,200	4,700	1,550	1,940
95	.15	.32	16.2	34.6	1,100	2,300	1,700	2,140
97.5	.08	.16	17.9	35.8	500	1,200	1,780	2,230
ESTIMATES FOR THE YEAR 2000								
50	----------	7.70	----------	$15.4	(5,900)	57,800	----------	----------
60	----------	6.15	----------	18.5	(5,900)	45,200	----------	----------
70	----------	4.62	----------	32.4	(5,900)	34,400	1,500	3,180
80	0.90	3.08	$14.5	49.2	5,990	22,700	1,820	3,840
90	.45	1.54	20.2	69.0	3,300	11,400	2,200	4,600
95	.22	.77	23.8	83.3	1,700	5,700	2,420	5,050
97.5	.11	.40	24.6	89.6	800	2,900	2,530	5,300

TABLE 10.—*Basin data sheet for Upper Mississippi River region*

Basic data: k_2, 0.17; temp., 74; C_s, 8.6 p.p.m.; D_4, 4.6 p.p.m.; N, 2.5. Water required, 1980 and 2000, in mil. g.d.: 1,759 and 2,535. Waste water discharge in mil. g.d.: 783 and 1,405.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50	----------	9.0	----------	$18.0	----------	15,500	----------	----------
60	----------	7.2	----------	21.6	----------	12,400	----------	----------
70	5.0	5.4	$35.0	37.8	8,400	9,400	6,000	2,600
80	3.3	3.6	53.0	57.5	5,600	6,200	7,200	3,200
90	1.7	1.8	76.5	81.0	2,900	3,100	8,800	3,920
95	.85	.9	91.8	97.8	1,450	1,500	9,680	4,310
97.5	.43	.45	96.3	101.0	700	760	10,100	4,510
ESTIMATES FOR THE YEAR 2000								
50	----------	15.5	----------	$31.0	----------	26,800	----------	----------
60	----------	12.4	----------	37.2	----------	21,300	----------	----------
70	----------	9.3	----------	66.0	----------	16,000	8,600	4,800
80	4.5	6.2	$72.0	98.0	7,700	10,600	10,400	5,750
90	2.3	3.1	103.0	140.0	4,000	5,300	12,700	7,040
95	1.15	1.6	124.0	173.0	2,000	2,700	14,000	7,750
97.5	.6	.8	134.5	179.4	1,000	1,300	14,600	8,100

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 11.—*Basin data sheet for lower Mississippi River region*

Basic data: k_3, 0.32; Temp., 80; C_s, 8 p.p.m.; D_4, 4 p.p.m.; N, 2.0. Water required, 1980 and 2000, in mil. g.d.: 387 and 546. Waste water discharge in mil. g.d.: 452 and 1,716.

[Pollution loads, treatment costs, b.o.d., and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50	----------	4.45	----------	$8.9	(3,100)	9,700	----------	----------
60	----------	3.56	----------	10.7	(3,100)	7,700	----------	----------
70	1.40	2.68	$9.8	18.8	3,100	5,600	1,320	1,540
80	.94	1.78	15.0	28.5	2,100	3,900	1,580	1,850
90	.47	.89	21.0	40.0	1,000	2,000	1,930	2,280
95	.24	.45	25.9	48.6	500	1,000	2,120	2,510
97.5	.12	.22	26.9	49.4	200	500	2,220	2,620
ESTIMATES FOR THE YEAR 2000								
50	----------	15.0	----------	$30.0	(2,900)	32,800	----------	----------
60	----------	12.0	----------	36.0	(2,900)	26,300	----------	----------
70	----------	9.0	----------	63.0	(2,900)	19,700	1,850	5,830
80	1.30	6.0	$20.8	95.0	2,900	13,200	2,240	7,030
90	.65	3.0	28.2	135.0	1,400	6,600	2,720	8,600
95	.33	1.5	35.6	162.0	700	3,300	3,000	9,460
97.5	.16	.8	36.8	179.0	400	1,600	3,130	9,900

TABLE 12.—*Basin data sheet for Upper Missouri River region*

Basic data: k_3, 0.25; temp., 68; C_s, 9.2 p.p.m.; D_4, 5.2 p.p.m.; N, 1.0. Water required, 1980 and 2000, in mil. g.d.: 618 and 867. Waste water discharge, in mil. g.d.: 175 and 1,134.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50	----------	5.8	----------	$11.7	(8,900)	25,800	----------	----------
60	----------	4.7	----------	14.1	(8,900)	20,600	----------	----------
70	2.0	3.5	$14.0	24.5	8,900	15,500	2,100	590
80	1.0	2.34	16.0	37.5	4,400	10,300	2,520	720
90	.5	1.17	23.0	53.0	2,200	5,200	3,080	875
95	.3	.6	27.0	64.8	1,100	2,600	3,390	962
97.5	.2	.3	29.1	67.3	600	1,300	3,540	1,000
ESTIMATES FOR THE YEAR 2000								
50	----------	9.0	----------	$18.0	(7,500)	39,600	----------	----------
60	----------	7.2	----------	21.6	(7,500)	31,800	----------	----------
70	----------	5.4	----------	37.8	(7,500)	23,200	2,950	3,850
80	1.7	3.6	$27.0	57.5	7,500	15,500	3,560	4,650
90	.85	1.8	38.0	80.0	3,700	7,700	4,330	5,660
95	.4	.9	43.2	97.2	1,900	3,900	4,760	6,230
97.5	.2	.45	44.8	101.0	900	1,900	5,000	6,500

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 13.—*Basin data sheet for Lower Missouri River region*

Basic data: k_3, 0.29; temp., 74; C_s, 8.8 p.p.m.; D_4, 4.8 p.p.m.; N, 1.0. Water required, 1980 and 2000, in mil. g.d.: 279 and 368. Waste water discharge in mil. g.d.: 110 and 370.

[Pollution loads, treatment cost, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50		1.40		$2.8	(1,400)	2,200		
60		1.12		3.4	(1,400)	1,700		
70	0.9	.84	$6.3	5.7	1,400	1,300	950	374
80	.6	.56	9.6	9.0	900	900	1,140	450
90	.3	.28	13.5	12.6	500	500	1,400	550
95	.15	.14	16.2	15.1	200	200	1,540	605
97.5	.08	.07	17.9	15.7	100	100	1,610	633
ESTIMATES FOR THE YEAR 2000								
50		3.4		$6.8	(1,080)	5,300		
60		2.7		8.1	(1,080)	4,200		
70		2.04		14.3	(1,080)	3,200	1,250	1,090
80	0.70	1.36	$11.2	21.8	1,080	2,130	1,510	1,310
90	.35	.68	15.8	30.5	500	1,100	1,840	1,600
95	.18	.34	19.4	36.7	300	500	2,060	1,760
97.5	.09	.17	20.2	38.1	200	300	2,140	1,840

TABLE 14.—*Basin data sheet for Upper Arkansas-Red Rivers region*

Basic data: k_3, 0.23; temp., 78; C_s, 8.3 p.p.m.; D_4, 4.3 p.p.m.; N, 0.75. Water required, 1980 and 2000, in mil. g.d., 419 and 581. Waste water discharge in mil. g.d.: 33 and 219.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50		1.4		$2.8	(14,900)	13,100		
60		1.12		3.4	(14,900)	10,400		
70	1.60	.84	$11.2	5.9	14,900	8,000	1,420	112
80	1.07	.56	17.0	9.0	9,900	5,200	1,820	136
90	.53	.28	23.8	12.6	4,900	2,600	2,100	165
95	.26	.14	28.1	15.1	2,500	1,300	2,310	182
97.5	.13	.07	29.1	15.7	1,200	700	2,420	190
ESTIMATES FOR THE YEAR 2000								
50		2.35		$4.7	(13,100)	21,900		
60		1.87		5.6	(13,100)	17,500		
70		1.41		9.9	(13,100)	13,100	1,970	745
80	1.4	.94	$22.4	15.0	13,100	8,800	2,400	900
90	.7	.47	31.5	21.1	6,500	4,300	2,900	1,090
95	.4	.24	43.0	25.9	3,300	2,200	3,190	1,200
97.5	.2	.12	45.0	26.9	1,600	1,100	3,340	1,260

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 15.—*Basin data sheet for Lower Arkansas-Red-White Rivers region*

Basic data: k_2, 0.24; temp., 82; C_s, 8.0 p.p.m.; D_4, 4.0 p.p.m.; N, 2.0. Water required, 1980 and 2000, in mil. g.d., 341 and 432. Waste water discharge in mil. g.d.: 330 and 770.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50	----------	2.34	----------	$4.60	(5,000)	9,800	----------	----------
60	----------	1.87	----------	5.62	(5,000)	7,900	----------	----------
70	1.2	1.40	$8.40	9.84	5,000	5,900	1,160	1,467
80	.8	.92	12.80	14.70	3,400	3,800	1,400	1,770
90	.4	.46	18.0	21.13	1,700	2,000	1,705	2,160
95	.2	.24	21.6	26.0	800	1,000	1,880	2,380
97.5	.1	.12	22.4	26.9	400	500	1,960	2,480
ESTIMATES FOR THE YEAR 2000								
50	----------	5.10	----------	$10.20	(3,800)	21,400	----------	----------
60	----------	4.08	----------	14.50	(3,800)	17,100	----------	----------
70	----------	3.06	----------	21.42	(3,800)	12,800	1,121	2,615
80	0.9	2.04	$14.4	32.70	3,800	8,600	1,353	3,160
90	.4	1.02	20.21	46.00	1,900	4,300	1,650	3,850
95	.23	.51	24.9	55.0	900	2,100	1,820	4,240
97.5	.12	.26	26.9	58.3	500	1,100	1,900	4,430

TABLE 16.—*Basin data sheet for Upper Rio Grande-Pecos Rivers region*

Basic data: k_2, 0.24; temp., 83; C_s, 7.8 p.p.m.; D_4, 3.8 p.p.m.; N, 1.0. Water required, 1980 and 2000, in mil. g.d.: 159 and 270. Waste water discharge in mil. g.d.: 12 and 387.

[Pollution loads, treatment cost, b.o.d. and algae dilutions]

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
ESTIMATES FOR THE YEAR 1980								
50	----------	1.00	----------	$2.0	(6,400)	10,700	----------	----------
60	----------	.8	----------	2.4	(6,400)	8,500	----------	----------
70	0.6	.6	$4.2	4.2	6,400	6,400	540	41.0
80	.4	.4	6.4	6.4	4,300	4,300	652	49.0
90	.2	.2	9.0	9.0	2,100	2,100	795	60.0
95	.1	.1	10.8	10.8	1,100	1,100	875	66.0
97.5	.05	.05	11.2	11.2	500	500	915	69.0
ESTIMATES FOR THE YEAR 2000								
50	----------	2.0	----------	$3.0	(8,500)	16,000	----------	----------
60	----------	1.6	----------	3.6	(8,500)	12,900	----------	----------
70	----------	1.2	----------	6.3	(8,500)	9,600	917	1,315
80	0.8	.8	$12.0	9.6	8,500	6,500	1,105	1,585
90	.4	.4	18.0	13.5	4,300	3,100	1,350	1,955
95	.2	.2	21.6	14.9	2,100	1,400	1,480	2,130
97.5	.1	.1	22.2	18.2	1,100	700	1,550	2,220

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 17.—*Basin data sheet for western gulf region*

Basic data: k_2, 0.25; temp., 85; C_s, 7.6 p.p.m.; D_t, 3.6 p.p.m.; N, 1.0. Water required, 1980 and 2000, in mil. g.d.: 1,170 and 1,750. Waste water discharge in mil. g.d.: 405 and 945.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

ESTIMATES FOR THE YEAR 1980

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
50	----------	7.15	----------	$14.3	(15,600)	27,800	----------	----------
60	----------	5.70	----------	17.1	(15,600)	20,200	----------	----------
70	4.7	4.30	$32.9	30.0	15,600	15,100	3,980	4,450
80	3.12	2.86	48.2	46.0	10,300	10,100	4,800	5,350
90	1.56	1.43	69.5	65.0	5,200	5,100	5,850	6,540
95	.78	.72	84.3	77.8	2,600	2,500	6,440	7,180
97.5	.39	.36	87.4	80.7	1,300	1,300	6,730	7,530

ESTIMATES FOR THE YEAR 2000

50	----------	18.5	----------	$37.0	(15,200)	65,300	----------	----------
60	----------	14.8	----------	44.4	(15,200)	52,800	----------	----------
70	----------	11.1	----------	77.7	(15,200)	39,100	5,950	13,570
80	4.6	7.4	$74.0	119.0	15,200	26,600	7,200	16,370
90	2.3	3.7	103.0	167.0	7,600	13,200	8,750	19,900
95	1.2	1.9	130.0	205.0	3,800	6,600	9,630	21,900
97.5	.6	1.0	134.5	224.0	1,900	3,300	10,200	22,900

TABLE 18.—*Basin data sheet for Colorado River region*

Basic data: k_2, .29; temp., 80; C_s, 8 p.p.m.; D_t, 4 p.p.m.; N, 1.5. Water required, 1980 and 2000, in mil. g.d.: 397 and 647. Waste water discharge in mil. g.d.: 9 and 175.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

ESTIMATES FOR THE YEAR 1980

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
50	----------	0.60	----------	$1.2	(6,700)	3,700	----------	----------
60	----------	.48	----------	1.5	(6,700)	2,900	----------	----------
70	1.10	.36	$7.7	2.8	6,700	2,220	1,350	30
80	.73	.24	11.7	3.8	4,500	1,400	1,640	37
90	.37	.12	16.7	5.4	2,300	800	1,980	45
95	.19	.06	20.5	6.5	1,100	400	2,180	49
97.5	.10	.03	22.4	6.7	500	200	2,280	52

ESTIMATES FOR THE YEAR 2000

50	----------	2.75	----------	$5.5	(7,300)	16,800	----------	----------
60	----------	2.2	----------	6.6	(7,300)	13,400	----------	----------
70	----------	1.65	----------	11.2	(7,300)	10,100	2,200	595
80	1.2	1.10	$19.2	17.6	7,300	6,700	2,650	720
90	.6	.55	27.0	24.8	3,700	3,400	3,230	875
95	.3	.28	32.3	30.2	1,800	1,700	3,550	963
97.5	.15	.14	33.6	31.4	900	800	3,720	1,010

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 19.—*Basin data sheet for Great Basin region*

Basic data: k_2, 0.25; temp., 75; C_s, 8.4 p.p.m.; D_0, 4.4 p.p.m.; N, 1.0. Water required, 1980 and 2000, in mil. g.d.: 345 and 579. Waste water discharge in mil. g.d.: 44 and 229.

[Pollution loads, treatment cost, b.o.d. and algae dilutions]

ESTIMATES FOR THE YEAR 1980

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
50	----------	2.2	----------	$4.4	(2,000)	19,200	----------	----------
60	----------	1.76	----------	5.3	(2,000)	15,300	----------	----------
70	0.24	1.32	$1.8	8.6	2,000	11,500	590	50
80	.16	.88	2.6	14.0	1,400	7,800	700	60
90	.08	.44	3.6	20.0	700	3,800	850	74
95	.04	.22	4.3	23.8	400	1,900	935	81
97.5	.02	.11	4.5	24.6	200	1,000	980	85

ESTIMATES FOR THE YEAR 2000

50	----------	2.8	----------	$5.8	(2,300)	24,100	----------	----------
60	----------	2.32	----------	7.0	(2,300)	19,900	----------	----------
70	----------	1.74	----------	12.2	(2,300)	15,300	660	260
80	0.27	1.18	$4.30	19.0	2,300	9,900	800	315
90	.18	.58	8.1	26.0	1,600	5,000	970	320
95	.09	.30	9.7	32.4	800	2,600	1,070	407
97.5	.05	.15	11.2	33.6	400	1,300	1,120	425

TABLE 20.—*Basin data sheet for South Pacific region*

Basic data: k_2, 16; temp., 83; C_s, 7.8 p.p.m.; D_0, 3.8 p.p.m.; N, 1.0. Water required, 1980 and 2000, in mil. g.d.: 1,150 and 1,800. Waste water discharge in mil. g.d.: 571 and 182.

[Pollution loads, treatment cost, b.o.d. and algae dilutions]

ESTIMATES FOR THE YEAR 1980

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
50	----------	2.5	----------	$5.0	(24,500)	19,100	----------	----------
60	----------	2.0	----------	6.0	(24,500)	15,300	----------	----------
70	3.2	1.5	$22.4	10.5	24,500	11,400	3,910	194
80	2.1	1.0	33.6	16.0	16,100	7,600	4,700	234
90	1.06	.5	47.5	22.5	8,000	3,800	5,750	285
95	.53	.25	57.3	27.0	4,000	1,900	6,330	314
97.5	.27	.13	60.5	29.1	2,000	1,000	6,600	330

ESTIMATES FOR THE YEAR 2000

50	----------	7.0	----------	$14.0	(25,900)	53,600	----------	----------
60	----------	5.6	----------	16.8	(25,900)	42,700	----------	----------
70	----------	4.2	----------	39.4	(25,900)	32,200	6,100	535
80	3.4	2.8	$54.5	45.0	25,900	21,400	7,300	750
90	1.7	1.4	76.5	63.0	13,000	10,500	9,000	910
95	.90	.7	97.3	75.6	6,500	5,200	9,900	1,000
97.5	.45	.35	101.0	78.5	3,300	2,600	10,350	1,050

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

TABLE 21.—*Basin data sheet for Central Pacific region*

Basic data: k_1, 0.4; temp., 68; C_s, 9.2 p.p.m.; D_t, 5.2 p.p.m.; N, 3.0. Water required, 1980 and 2000, in mil. g.d.: 850 and 1,430. Waste water discharge in mil. g.d.: 190 and 550.

[Pollution loads, treatment cost, b.o.d. and algae dilutions]

ESTIMATES FOR THE YEAR 1980

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
50	----------	4. 25	----------	$8. 5	(6, 200)	9, 500	----------	----------
60	----------	3. 40	----------	10. 2	(6, 200)	7, 600	----------	----------
70	2. 8	2. 54	$19. 6	17. 78	6, 200	5, 700	2, 890	646
80	1. 86	1. 70	29. 8	27. 2	4, 100	3, 800	3, 480	780
90	. 93	. 85	41. 8	38. 2	2, 100	1, 900	4, 250	950
95	. 47	. 43	50. 8	46. 5	1, 000	900	4, 680	1, 045
97.5	. 24	. 22	53. 8	49. 3	500	500	4, 960	1, 100

ESTIMATES FOR THE YEAR 2000

50	----------	9. 5	----------	$19. 0	(7, 600)	21, 200	----------	----------
60	----------	7. 6	----------	22. 8	(7, 600)	17, 000	----------	----------
70	----------	5. 7	----------	39. 9	(7, 600)	12, 700	4, 910	1, 870
80	3. 4	3. 8	$54. 6	59. 3	7, 600	8, 500	5, 930	2, 260
90	1. 7	1. 90	76. 5	85. 5	3, 800	4, 200	7, 240	2, 750
95	. 9	. 95	97. 3	102. 8	1, 900	2, 100	7, 960	3, 020
97.5	. 5	. 50	112. 0	112. 0	900	1, 000	8, 330	3, 160

TABLE 22.—*Basin data sheet for Pacific Northwest*

Basic data: k_1, 0 25; temp. 65; C_s, 9.5 p.p.m.; D_t, 5.5 p.p.m.; N, 2.0. Water required, 1980 and 2000, in mil. g.d.: 1,060 and 1,700. Waste water discharge in mil. g.d.: 4,400 and 10,000.

[Pollution loads, treatment costs, b.o.d. and algae dilutions]

ESTIMATES FOR THE YEAR 1980

B.o.d. removal (percent)	Population equivalent load		Annual treatment cost		Required total streamflow for—			
					B.o.d. dilution (C-1)		Algae dilution (C-2)	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
	Millions	*Millions*	*Millions*	*Millions*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*	*Mil. g.d.*
50	----------	12. 9	----------	$25. 8	(4, 800)	28, 900	----------	----------
60	----------	10. 3	----------	31. 0	(4, 800)	24, 100	----------	----------
70	2. 1	7. 7	$14. 7	54. 2	4, 800	17, 300	3, 700	6, 450
80	1. 4	5. 2	17. 0	83. 4	3, 100	12, 000	4, 350	7, 740
90	. 7	2. 6	31. 0	116. 1	1, 160	6, 000	5, 300	9, 460
95	. 35	1. 3	37. 8	139. 3	8. 00	3, 000	5, 830	10, 400
97.5	. 2	. 6	44. 9	144. 5	400	1, 500	6, 100	10, 880

ESTIMATES FOR THE YEAR 2000

50	----------	19. 8	----------	$39. 6	(5, 000)	45, 900	----------	----------
60	----------	15. 8	----------	47. 5	(5, 000)	36, 400	----------	----------
70	----------	11. 9	----------	83. 2	(5, 000)	27, 500	5, 800	7, 480
80	2. 2	7. 9	$35. 0	126. 5	5, 000	18, 200	7, 000	9, 000
90	1. 1	4. 0	50. 0	178. 2	2, 500	9, 100	8, 500	11, 000
95	. 6	2. 0	64. 8	213. 8	1, 300	4, 600	9, 350	12, 100
97.5	. 3	1. 0	67. 2	222. 2	600	2, 300	9, 730	12, 650

NOTE.—No dilutions were calculated below 70-percent treatment in 1980 and 80-percent treatment in 2000.

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